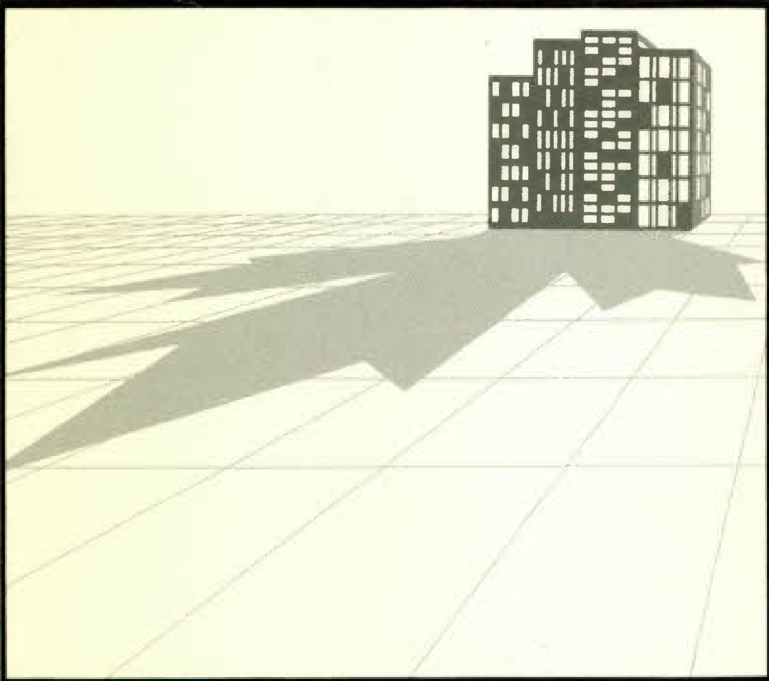
Atomic Energy of Canada Limited

The Crown Corporation as Strategist in an Entrepreneurial, Global-Scale Industry



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A ... epared for the
E ... Council of Canada

Atomic Energy of Canada Limited

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Foreword

This study was undertaken as a part of the Council's project on government enterprise. The overall aim of this project – the results of which were published in late 1986 under the title *Minding the Public's Business* – has been to improve our understanding of federally and provincially owned and controlled entities which operate at arm's length from government and have important commercial functions. The project has attempted, more specifically, to address two specific questions: What is the appropriate role of government enterprise as one of a number of instruments of public policy? And, second, how should the apparatus of control within government be structured so as to realize the full potential of this instrument?

The research undertaken for the project has included both the examination of general questions pertaining to government ownership and the investigation of the performance of particular firms and sectors. This monograph by George Lermer is the result of one of the case studies prepared for the project. The problems besetting Canada's nuclear reactor industry have been the subject of much discussion over the years. In this study, Professor Lermer provides an assessment of the costs and benefits of the CANDU system, and looks more generally at the use of a public enterprise for the development and commercialization of a complex technology. Because the development of CANDU was necessarily a long and costly process and one that entailed an especially high degree of commercial risk, it is the type of venture for which one might expect some government involvement or support. Atomic Energy of Canada Limited's experience can tell us something about the advantages and the pitfalls of such involvement when the government's response takes the form of a public enterprise.

George Lermer has written widely on economic and Canadian public policy issues. He is presently Director of the School of Management at the University of Lethbridge.

Judith Maxwell
Chairman

Preface

Too many persons contributed to the writing of this study to acknowledge them all here. Nor am I certain everyone I spoke to would like to be identified with my work because my conclusions are pessimistic for the future of Canada's nuclear reactor industry. Stated more accurately, the study is pessimistic about the prospects for the profitable export of the CANDU nuclear reactor technology. This is partly because the Crown corporation form of enterprise is found to be a weak organizational structure for commercializing a new technology in a highly competitive worldwide market. In the past, political constraints and political outlooks influenced the style of organization that AECL became, and in my judgement this led AECL injudiciously to focus on development of the CANDU for the Canadian market alone. It failed to grasp the importance of establishing credibility as a commercial success in international markets, and to overcome potential foreign buyers' concerns about the key weaknesses in the CANDU system. Despite the reorganization of AECL which began in 1978, there is little reason to expect that AECL will today be able to reverse the commercial fortunes of the CANDU reactor system.

This study provides a new cost/benefit analysis in order to establish a measure of AECL's success or failure, and to provide a basis for considering further public investments to sustain the industry. At this time, despite the many disappointments in the development of the CANDU system, it appears that in Ontario the CANDU is a cheaper option than coal. Ontario saves about $800/kW (1981 dollars) by adopting the CANDU instead of coal technology, while the federal government has invested through R&D support for AECL about an equal amount, which as it has turned out has been almost exclusively for the benefit of Ontario electricity users. But coal may not have been the best alternative to nuclear-generated power using the CANDU system. Ontario Hydro might have opted for a light-water reactor instead of the CANDU. It is estimated that Ontario saves at most a modest amount, just $41/kW (1981 dollars) by adopting the CANDU instead of a U.S. designed light-water reactor. So the CANDU is for Ontario a good technology for expanding its generating capacity as long as the province fails to take into account its citizen's share of the federal contribution. The federal government's sunk costs are about $12 billion (1981 dollars) for R&D support or about $800/kW (1981 dollars), and it is doubtful if these costs will ever be recovered.

Politicians in Ontario and Canada found the CANDU system an irresistible project. It promised simultaneously to make use of domestic resources and displace imports, be profitable and give Canada a high prestige hi-tech project. Yet it was not inevitable that the project be undertaken by a public sector firm. The study finds numerous weaknesses in the public sector mode for commercializing the CANDU. Unfortunately, it has little to say about what would comprise the optimal organizational structure.

There is much further work needed concerning the development of managerial structures to govern major technological projects and to commercialize them. Though major firms do this all the time, there are many inexplicable successes and equally strange failures. I was reminded on writing this foreward about Sayles and Chandler's book (1971) on the National Aeronautic and Space Administration (NASA), one organization that today is tattered if not shattered. But the Sayles and Chandler book was one of the few I could find that addressed the enormous problems of managing complex technological projects, let alone commercializing them. I was reminded also of Oliver Williamson's (1985) assessment that we know little about how bureaucratic structures cope with transactions costs. He wrote that, "By comparison with the market failure literature, the literature on bureaucratic failure is relatively underdeveloped" (p. 149). Moreover, Williamson concludes that, "the study of economic organization in a regime of rapid innovation poses much more difficult issues" (p. 143) and he hopes that studies of extreme cases (possibly like the CANDU developed by AECL) will provide valuable data for scholars striving to enlarge the theory of optimal organizational forms. This case study is offered in response to Williamson's call, but at the same time it provides a new look at certain specific questions of Canadian nuclear reactor development policy that are rarely off Ottawa's agenda.

Ron Hirshhorn and Abe Tarasofsky from the Economic Council initiated this study and provided valuable guidance along the way. Comments on an earlier draft by Don McFetridge, Graham Smith and Don Meneley are much appreciated even if they find that their advice led me to make only minor changes in the final version. Concerns of three anonymous reviewers have influenced this study especially in terms of its organization and presentation. Senior personnel at Ontario Hydro and the Atomic Energy of Canada Limited were helpful, but they have not provided me with a critique of the study and for obvious reasons they may be less than enthusiastic supporters of my findings. Helpful too were personnel concerned with nuclear issues at the Department of Energy, Mines and Resources. The typing of this study was largely done by Gail Kembel, and it is a pleasure to acknowledge her efforts to meet my frequent last minute deadlines. It is a pleasure also to thank Toby Lermer and Jill Sinkewich who assisted with collecting the many sources the study relies upon for data. Finally, I would like to recognize the Council's editorial staff for sharpening up considerably the prose style of an earlier draft.

Atomic Energy of Canada Limited

1 Introduction

The Atomic Energy of Canada Limited (AECL), is the organization established by the Canadian government primarily for the purpose of commercializing the Canada Deuterium and Uranium (CANDU) nuclear reactor system. In order to evaluate the performance of AECL, this study marshalls three methodologies – organization theory, business strategy and cost/benefit analysis. The first methodology used, organization theory, asks how organizations are structured along various relevant dimensions in order to reduce the transactions as well as the material costs of production. The theory is used here to identify features of the private organization that emerge as means of reducing costs, and to examine by contrast the organizational characteristics of AECL. The second approach, the business strategy literature, offers the manager advice about how to improve his firm's financial performance. The advice is based on various paradigms and correlates of success that have emerged from numerous case studies of business organizations. The business strategy approach is used here to ask if AECL has adopted the advice that flows from strategic analysis, and if not why it has failed to do so. Finally, cost/benefit analysis provides calculations of the expected net benefits of projects. It is used here to examine if Canadian taxpayers earned an adequate return on their past investments in the development of the CANDU system, and if further investments are advisable. Though not central to the purposes of this study, without a cost/benefit analysis we would be unable to fix quantitative measures of AECL's degree of success or failure.

The study proceeds in Chapter 2 to provide rationales for an additional case study of AECL. This case study of AECL is presented as a means of assessing the merits of the arguments that the Crown corporation may be an effective instrument for fostering dynamic comparative advantage in high-technology industries. The chapter elaborates how popular their public policy is in Canada, and also how often the CANDU project's performance is used to support the case for greater government investments in high-technology industries.

In Chapter 3, the writer places in context the case study to follow by outlining both theoretical and political factors that affect the relative efficiency of public as compared with private firms. The theoretical section of the chapter sets out straightforwardly what organization theory has to say about the choice between a public and a private firm. The final section of the chapter examines how Canada came to commercialize the CANDU system in the public sector.

In Chapter 4, there is first a brief review of concepts of strategic management as they are to be applied to AECL. This is followed by sections that outline how AECL's capacity to set its own strategy is linked to first its capital market, second its internal constituencies and third its product market. The latter sections are followed by one that explores how the U.S. and French nuclear industries developed well articulated strategies. This section is a prelude to the final sections of the chapter which examine the unsuccessful Canadian business strategy for commercializing the CANDU. AECL first focussed on the domestic market, neglecting the export market especially in developed countries. AECL's strategy was to focus on Ontario, and in third world markets to stress how the CANDU differed from the competitors' products.

AECL failed to implement a successful strategy during a period of expanding demand for nuclear reactors. Today, demand is declining. Strategy formulation is often more difficult when demand is declining. This is the subject of Chapter 5. The chapter first examines the extent to which demand for nuclear reactors has declined and reviews forecasts for future markets. It then considers the two major competitors for the CANDU – first other nuclear reactor designs and second the cost of coal-generated electricity.

In Chapter 6 we present new cost/benefit calculations for the CANDU nuclear reactor system, which lead to the conclusion that the CANDU is not a financial success and it is unlikely that CANDU will repay the additional investments still needed to give it some hope for commercial success in the future.

The conclusions of the study are collected and presented in the final chapter.

2 Rationales for Undertaking this Case Study

Objectives of this Study

This case study examines the development of the Canada Deuterium and Uranium (CANDU) nuclear reactor system by Atomic Energy of Canada Limited. (AECL). Though much has been written about AECL, CANDU, and the nuclear reactor business, whether Canada's efforts to commercialize the CANDU system is a success or failure remains controversial. Recently, one writer concluded that "CANDU may not have reached an economic break-even point yet, nor even provided a net social benefit contribution." (Palda 1984, p. 101). This conclusion stands in sharp contrast to that of many other studies affirming CANDU's success. This study, among other things, contributes an additional and detailed cost calculation of the federal government's involvement in the CANDU project.

A cost/benefit analysis of a controversial and giant corporation like AECL needs little justification. Curiosity alone about such an organization, with assets well above $1 billion is sufficient reason for the undertaking. Trebilcock and Prichard have reported that in 1978 AECL was larger – measured on the basis of book value of assets – than Air Canada, the Canadian Broadcasting Corporation, the Federal Business Development Bank, or the St. Lawrence Seaway Authority (Prichard [ed.], 1983, pp. 1, 95). That year, AECL's 1.5 billion dollars' worth of assets represented over 5 per cent of the assets of all federal government Crown corporations, excluding the Bank of Canada. Palda described the CANDU nuclear reactor project as "the grand-daddy of high-technology ventures in Canada ... and it very likely still represents the single, most expensive, active hi-tech project around" (1984, p. 100).

While a cost/benefit analysis in itself is valuable, this study has a broader purpose. Its main purpose is to adduce from this one example some general lessons that might be applicable to an important public policy issue. The general issue is the potential for a Crown corporation type of corporate organization to act as an instrument for commercializing new technologies, especially when the new technologies must be commercialized in an international market, in competition with other countries vying to launch their own firms. This study is, therefore, especially timely because today the Canadian government is actively considering expanding its support for high-technology industries.

Several official councils, commissions, and task forces have been studying and/or advocating increased government support for high-technology industries. The Science Council of Canada (1979), which includes among its members several senior industrial leaders, is identified as an active proponent of government support for high-technology industries. The Royal Commission on the Economic Union and Development Prospects for Canada (the Macdonald Commission 1985) has devoted considerable attention to researching this issue. The importance of the issue is reflected in the appointment by the federal government of a Task Force on Federal Policies and Programs for Technology Development (1984), which recently published a report. In *A New Direction for Canada* (Canada, Dept. of Finance 1984, p. 25), the federal government placed R&D, innovation, and technology diffusion at the top of its list of economic challenges to be addressed during the government's present term of office.

Popularity of Government Intervention

The federal government's orientation towards "laissez-faire" in the high-technology field confirms Marsha Chandler's thesis (Prichard [ed.], 1983) that Conservative governments are as prone as left-wing regimes to sponsor Crown corporations in certain fields. She pointed out with regard to provincial Crown corporations, that

> to promote rather than control is a policy tool well within the ideological ken of nonsocialists. Based on the shared interest of the state and the private sector, it involves the use of the state to further those interests (Prichard [ed.], 1983, p. 215).

Chandler noted, further, that there are four fields in which Conservative governments are prone to invest through Crown corporations. The four are: industrial development; research and development; power; and transportation. Since nuclear reactor development fits into three of the above four categories, it is no surprise that AECL and the CANDU reactor program is well positioned to enjoy both federal and provincial support regardless of the ideological predisposition of the governments concerned. Chandler's thesis is further confirmed in the

Alberta government's recently published White Paper (Alberta 1984). In it, the most conservative government in Canada approves policies that focus on high-technology industries. In a tone that borrows much from U.S. literature that is pro-interventionist about industrial policy, the White Paper advocates government identifying winners in growth sectors and subsidizing specific firms. Chandler has also concluded that Crown corporations are an attractive political option for Canadian governments.

Nor is academic opinion unanimously hostile to an expansion of government intervention on behalf of selected high-technology projects. In a recent study for the Macdonald Commission, Richard Harris also advocated government intervention to foster high-technology industry. He argued that

> the development of new export markets by entry of domestic firms into a world concentrated industry is bound to be difficult ... policy to deal with the transitional difficulty should be an important concern for Canada (Harris 1984, p. 8).

Harris, otherwise noted for his studies documenting the advantages for Canada of free-trade policies, did not explicitly identify Crown corporations as the vehicle for fostering government support for Canadian high-technology industries. But others are prepared to advocate reliance upon Crown corporations as one major thrust in Canada's efforts to build high-technology industries.

In a brief submitted to the Wright Task Force, J.A.L. Robertson (1984), on behalf of Atomic Energy of Canada Limited Research Company, argued that

> The success of the AECL model for technology development can be judged to the extent to which we have achieved our objectives.

After judging the CANDU to be a "world leader in performance, economy, and resource conservation," Robertson argued that

> On the abstract level, perhaps our single most important contribution to today's policy discussions is the demonstration that Canada can produce world class products in areas of high technology. In this we align ourselves with those responsible for Canadian communications satellites, Telidon, the Canadarm, and short take-off and landing [STOL] aircraft (p. 2).

Robertson concluded that

> While the Canadian government operates several industry support programs to foster technology development; for example, DEPP, EDP, IRAP, and PILP, the use of Crown corporations for this purpose is also of *proven effectiveness* (p. 14).

Robertson's confidence cannot be dismissed as mere special pleading on behalf of AECL. Others have attributed to the CANDU project unqualified high marks for being a high-technology success story.

Assessments of CANDU's Success

Bruce Doern and Gordon Sims have described CANDU as "one of Canada's few internationally recognized technological successes" (1980, p. 49).

In 1978, James Gardner and Fred Belaire (Canada, EMR 1978) reported that

> the CANDU reactor has unquestionably demonstrated its technological efficiency and economic practicality (p. 134).

The Science Council of Canada (1979)

> has advocated the development of this (nuclear) energy technology for some time.... Canada must continue to play the lead role in the R, R&D necessary for further development of CANDU for at least the next two or three decades since practically all other nations have focused their attention on other reactor systems.... the technical, environmental and economic viability of the CANDU reactor system, using natural uranium, has been demonstrated by some 20 reactor-years of experience (p. 46).

After an extensive review of nuclear policy, Energy, Mines and Resources concluded that

> based on the *clear advantages* of the CANDU in generating electricity to meet domestic load growth (particularly east of Manitoba) orders will likely be placed in the latter part of the 1980s for domestic reactors to come on stream in the 1990s. Second, some reactor export markets appear promising ... and ... there appear to be attractive opportunities to prebuild nuclear reactors in Canada to export electricity to U.S. markets (Canada, EMR 1981*b*, p. 2).

Johnson (see McFetridge 1985) found that the CANDU reactor system enjoys a marked net cost advantage over light-water reactors. Her estimates suggest that with existing capacity alone the cost savings resulting from the CANDU system is in excess of CANDU's R&D costs. Richard Zuker and Glenn Jenkins (1984) evaluated the cost of additional hydro and coal electrical generating in Quebec and Ontario with nuclear plants. They did not distinguish CANDU from other nuclear options, but there can be little doubt that Zuker and Jenkins had in mind the CANDU system when they wrote about nuclear power development. Implicitly, therefore, they judged the CANDU a success, at least in relation to the cost of using coal for generating electricity.

Hydro-Québec, a utility that has been lukewarm at best to nuclear power, uses

> an 850 megawatt CANDU-type nuclear power plant, using natural uranium as fuel and heavy water as the coolant and moderator ... as the reference source in evaluating the economic feasibility of Quebec's hydro-electric potential (Hydro-Québec 1980, p. 75).

For Hydro-Québec in 1980, the CANDU – and not other nuclear alternatives or coal – was assumed to be the next best alternative to hydro as good sites for hydro development disappeared.

Ontario Hydro is pleased with its large investments in CANDU reactors. In 1982, Sligl summarized Ontario Hydro's findings as follows:

1. The accumulated discounted costs of nuclear generation, although initially higher, are lower than coal-fueled generation after two or three years.

2. Fuel costs provide the major contribution to the total lifetime costs for coal-fueled stations, whereas capital costs are the major item for the nuclear station.

3. The total unit cost of electricity from the nuclear station is less than the fuel cost alone for the coal-fueled station.

4. The break-even lifetime capacity factor between nuclear and coal-fueled generation is projected to be 5 per cent.

5. Large variations of various cost components are reduced before the cost advantage of nuclear generation is lost.

6. The total unit energy cost remains approximately constant throughout the station life for nuclear generation, while that for the coal-fueled station increases significantly due to escalating fuel costs (p. 20).

Milan Nastich, the President of Ontario Hydro, reported that

> we're continually continuing to build nuclear plants because we want to displace increasingly expensive fossil-fueled plants that still supply part of the basic electricity demand ... When we've finished our current building program, the province's basic electricity demand will be supplied solely by nuclear and hydro-electric generating plants.

And the proof of the remarkable success of the CANDU is that

> most U.S. utilities could buy nuclear generated electricity from Ontario for less than they could produce it for themselves from *any* fuel they have, including uranium (1981, pp. 33-36).

Nastich concluded that Ontario's nuclear power program represents "sound planning and foresight" that others might do well to emulate.

Case Studies or Theory in Public-Policy Analysis?

The writer of this study has quoted the above authorities at considerable length because it is important to appreciate the weight of opinion that gives the CANDU system not just passing marks but excellent grades. No wonder, then, that it is frequently held up as an example of policy effectiveness. Of course, the mere observation that AECL may be a success is not a sufficent basis on which to conclude that the Crown corporation is an efficient organizational form for fostering internationally competitive Canadian industries in high-technology fields. Public ownership ought not to be condemned simply because one public firm fails; nor should public ownership be advocated simply because of a single success. Case studies alone cannot be decisive in choosing between organizational models. Fortunately, there have been significant advances in the theoretical literature linking ownership and corporate structure to the effective performance of the firm. This literature has recently been reviewed independently first by Borcherding (Prichard [ed.], 1983) and later by McFetridge (1985) for the particular case of the Crown corporation. Hirshhorn (1984) applied the insights from the literature on corporate structure to government enterprises. Baldwin (1984) analysed the conditions under which public enterprise dominates regulation as an instrument of government policy. Unfortunately, the theoretical literature has not yet reached the point where a dominant paradigm governs the field. It is, therefore, unable to persuade policy analysts to take one course of action over another. Or having first decided upon a policy objective, theory fails to direct the analyst to the most efficient policy instrument. Borcherding pointed out that

> too many possibilities are being explained [by the theory of public supply arrangements] to be of great theoretical use so far (Prichard [ed.], 1983, p. 176).

The still tentative nature of conclusions from organizational theory about the choice between different instruments for the delivery of public policy makes every additional case study of a Crown corporation an important source of data for theorists. Borcherding stresses that a theory on public-sector supply should successfully differentiate those state activities that generate net wealth from others that transfer it. The latter are prone to be economically expensive, even if perceived to be an efficient mechanism for attaining political objectives. Until this distinction is well understood, Borcherding concluded that the proper role for Crown corporations will remain mired in ideologically intense speculations rather than rational and testable guidelines for policy (Prichard [ed.], 1983, p. 176).

Apart from the organizational theory that Borcherding reviewed for its applicability to the issue of public supply, there exists an extensive literature on the linkage between business strategy and corporate structure. Some writers, most notably Roderick White, writing from the point of view of the business strategy tradition, have looked at the strengths and weaknesses of AECL and other Canadian Crown corporations. The business strategy literature uses a comparative approach to evaluating a firm's performance. The method involves comparing a firm's conduct, performance, and organization with a standard that is thought to reflect "best practice." To establish a best-practice standard, the field collects those characteristics and features of business policy and organizational structure that are highly correlated with success.

From this perspective it is natural to ask whether or not AECL has performed well by those standards for managerial excellence recognized in the private sector; this study asks and answers just such questions.

In conclusion, it is suggested above that a case study like this one plays a dual role. In the absence of a dominant paradigm to guide public-policy controversies, an author must be conscious that his or her work will be used to advocate certain public policies. The more compelling the illustration of marked success or failure, the more useful the study for this advocacy function. Since all interest groups will search for those illustrations that favour their cause, we must rely upon an adversarial system to adjudicate between case studies. The second role is to provide more material for the theorist's grist mill, in the expectation that a consensus on an appropriate framework will emerge for both public-policy debates and analysis. By no stretch of the imagination, however, is a case study a neutral report of historical evidence. The case writer, therefore, owes it to readers of his case report to be as explicit as possible on two points – his own understanding of the underlying theory and his ideological bent. In the following section, the author of this study presents his own views contrasting them with those of others.

3 Private vs. Public Enterprise

The Onus of Proof

In this section the writer outlines why he believes that when a Crown corporation is being evaluated as an instrument for delivering commercial and political services, the onus for proving the affirmative case must rest with the proponents of the Crown corporation. The presumption should be, in every case, that the private corporate form is the more efficient instrument. The advocate for the Crown corporation must articulate the political objectives, consider the efficiency of alternative policy instruments, and forecast the loss in commercial efficiency that is acceptable in order to pay for delivering the identified political services.

The basis for this strong assertion is that private corporations enjoy virtually every organizational option available to the Crown corporation. It follows that a private corporation will be at least as effective an organizational form as a Crown corporation whenever effectiveness is measured by the firm's ability to maximize its value. What is conceded by some policy analysts is that the Crown corporation may be an efficient organizational form when the government is delivering a political service jointly with a commercial service. By attaching the political service to a commercial organization, the government may be able to reduce the cost of delivery below the level that would be incurred through an alternative policy instrument (Trebilcock et al. 1982).

Section A: Theoretical Considerations

Some theorists would argue that the deficiencies of the social mechanisms that induce efficient performance in privately-owned firms make the comparison between public and private firms irrelevant. According to this view, theory is silent on the choice between the public and the private firm. Somewhat less emphatically, others argue that though costs are likely to be higher in the public sector, they would be only slightly higher. For this group, then, the choice rests solely on the benefit of combining into one corporate structure the supply of public and commerical goods and services.

The Separation of Management from Ownership

Large commercially-oriented organizations in the private sector encompass numerous constituencies, both inside and outside the firm. Performance contracts, both implicit and explicit, bind the interests of all constituencies. Constituents include the firm's shareholders, its senior managers, its customers and suppliers, its creditors, its work force, as well as the communities within which the firm operates. Among the multiplicity of contractual relationships that bind those within and outside the firm, one that has received a great deal of attention is the relationship between owners and senior managers. This contractual arrangement is characterized by an agency relationship. The owner is the principal; the manager, his agent. Professional managers' self-interests may well differ from those of the owners. Alchian and Demsetz (1972) stressed that managers may shirk their duties towards shareholders in a variety of ways that may be difficult for owners to identify and correct. The same conflict was graphically described many years earlier by among others Berle & Means (1982).

For the latter group of authors, the consequences of the separation between ownership and management invited correction by either government ownership or regulation. For the former, government intervention did nothing to alleviate the agency problem, which might well be aggravated under government control. The costs associated with the agency problem are derived from two fundamental features of social organization – bounded rationality and opportunism – that exist both inside and outside government.

"Bounded rationality" refers to the limited capacity of humans to acquire, interpret, and retain information, which in turn gives rise to information asymmetries among persons, even in the same organization. "Opportunism" captures a wide range of behaviour, including distorting information, misrepresenting earlier agreements and understandings, plain bad faith, and honestly misinterpreting events and understandings. Bounded rationality and opportunism create additional costs for the parties seeking to contract future performances. It is inherently difficult to determine a contract that is enforceable in all future circumstances. Evidently, it is especially costly when parties to the contracting process withhold specialized information or distort the information they choose to communicate. The latter behaviour is called ex ante opportunism because it is aimed at influencing the contract itself. Opportunism extends also to ex post behaviour, which makes costly the monitoring and enforcement of contracts during the life of the contract. Since bounded rationality and opportunism are endemic to human society, the introduction of government may add to rather than detract from participants' opportunities to hide and distort information. For Michael Jensen and William Meckling, for instance, the governing structure of the modern corporation is a response to the costs that flow from the "agency" nature of the relationship between owners and managers (Jensen and Smith Jr. [eds.], 1984, pp. 78-133). The structure of the firm adapts in order to reduce agency costs. Adaptation will not enable the firm to eliminate the costs, but flexibility in contracting at the level of the capital market in management contracts and in the ownership structure of the firm leads progressively to the reduction of agency costs.

The "agency" issue is only one of many contracting issues that lead to transaction costs being incurred during the course of co-ordinating the activities of the firm. It is pivotal because senior managers are thought to have the means of controlling internally generated transaction costs. They have access to information and the authority to govern internal contract performance at reasonable cost through bureaucratic methods. The efficiency of hierarchical employer-employee relations will vary from circumstance to circumstance. Nonetheless, there have been developed numerous and sophisticated systems of job description, job evaluation, and performance measurement. Senior managers generally retain the right to reassign employees as circumstances alter. By contrast, senior managers, especially when ownership is dispersed, will have considerable freedom to select strategies for the firm, to invest and divest, and to alter the risk class of the firm. Thus, the authority to act is vested in just those persons with access to detailed information that is not readily available to the shareholders. It is certainly an oversimplification to describe bureaucratic control systems as perfectly efficient; but they are reasonably efficient mechanisms when one contrasts them with the potential for opportunism that pollutes contractual arrangements between shareholders and senior management.

From the simple analysis described above, it is clear that if the objective of the enterprise is to maximize the long-run economic return to the shareholders (equivalent to maximizing the value of the firm), a Crown corporation has few, if any, advantages over a private corporation. The private firm is free to adopt any bureaucratic technique that is available to the government enterprise. It also has access to capital from a financial market that permits creditors and owners of the firm to diversify their portfolios so that there is little additional risk reduction achieved through forcing taxpayers to own the government enterprise.

In the private sector, the ownership structure will be influenced by distinct pressures that operate in conflict with one another. On the one hand, shareholders and creditors will seek to reduce their risk by diversifying their holdings over many firms; on the other hand, diversification carried too far raises costs, and it exposes the investor to exploitation by managers. Managers will themselves wish to signal to potential investors that they are to be trusted. By so doing, they will be able to reduce the cost to themselves of the capital they raise on the market. But signaling may be costly, and credibility difficult to convey. Put simply, it is difficult for the manager to bond himself in such circumstances. For this reason, managers – or, more accurately, management teams – may find it economic to absorb the risk of underdiversified ownership and control the firm they are managing. For this reason, too, we observe in the world firms that are closely held and other firms in which ownership is widely dispersed.

We expect that ownership will be widespread for those firms when managerial performance can be readily monitored and supervised at low cost. In this case, owners and managers have little incentive to remain underdiversified. When such supervision is costly and expensive, however, diversified shareholders are exposed to a free-rider problem. All owners would share in the benefit of monitoring the managers, but each individual shareholder may rely on someone else to do the monitoring. Since information gathering, monitoring, and the supervising of managers is largely a fixed cost, owning a larger share of the firm reduces the per-unit cost of the task. Consequently, the more difficult it is to measure managerial performance, the more likely a corporation is to be closely held.

Four Social Mechanisms that Modify Agency Costs

Other social mechanisms modify the agency cost for the private firm. These include the market for managers, the product market, the takeover market, and the financial market. The market for managers is the arena in which individual managers compete against each other for higher compensation, advancement, power, and opportunities to build marketable human capital. When the product market is competitive and the firm is inefficient, the market swiftly weeds out the inefficient firms via failure. The takeover market is the arena in which teams of managers, often managing other firms, compete for the control of an organization by acquiring sufficient voting shares of the firm they believe they can run more profitably. Finally, the financial market allows investors and creditors to exit – that is, to disinvest – thereby signaling dissatisfaction with the firm's performance and prospects. This action increases the cost of capital to the firm, thereby reducing the incumbent management's opportunities to invest and making them vulnerable to a takeover by a management team enjoying a lower cost of capital.

The public sector shares with the private sector a market for managers. But in the public sector, managers are unable to take an equity position in the firm. Furthermore, management contracts have traditionally been limited by public-sector compensation guidelines stipulated by a bureaucratic model applicable to non-commercial organizations. The product market is thought to discipline both private and public corporations similarly; but, here, differences in the speed and effectiveness of the constraint will depend upon a variety of market characteristics. In the public sector, the takeover market is virtually non-existent, and the role of the financial market as an external constraint is muted. The cost of capital is what the government wishes it to be, and it is impossible to signal investor dissatisfaction in the stock market. The political pressure favouring the "privatization" of Crown corporations may act as a weak substitute for the takeover market in the private sector, but in the public case it is often the weak sisters that are retained in the public fold and the strong firms sold off. Nonetheless, one can imagine that the prospect of being privatized might serve to motivate a management team towards excellence in the expectation of being far better rewarded as managers of a private firm than of a public one.

Political Constraints

Public-sector firms are also controlled by a political marketplace. Politicians influence its direction and constrain the freedom of its managers, and politicians respond to the influence of "voice" in the political marketplace. Evidence on the effectiveness of mechanisms for reducing the agency costs of AECL will be presented in the context of the case study that follows in subsequent chapters. In the concluding section of this chapter evidence is gathered together and evaluated relative to the principles established in the theoretical literature. The latter is briefly reviewed below as it applies to AECL; and for a more complete review of the general literature, the reader is invited to consult Borcherding in Prichard ([ed.], 1983); McFetridge (1985); Hirshhorn (1984); Jensen and Smith, Jr. ([eds.], 1984); and Jensen and Zimmerman ([eds.], 1985).

The product market in which AECL operates makes it difficult to monitor the manager's performance. Research is inherently difficult to manage, as noted in Jauch (1983). But it is not only because AECL is a research company that its performance is difficult to evaluate; a more fundamental problem is that performance can only be judged in the long term by the success that AECL enjoys in profitably selling nuclear reactors in competition with its rivals. There is a long delay between the initiation of such a project and the time that a definitive evaluation of performance can be confidently made. The stages between conception and completion include research, demonstration, sale, construction, and time to gather operating experience. Even after decades, it is virtually impossible to separate ex ante efficient decision making from ex post efficiency. Success or failure is unavoidably dependent upon unanticipated shifts in the price of alternative sources of energy, in technological change, and in such uncontrollables as the rate of inflation and interest rates.

The nature of the nuclear reactor industry makes it especially difficult to decide upon its success or failure even today, 33 years after the incorporation of AECL. But that uncertainty about AECL's performance on an ex post basis even today is not sufficient reason for failing to evaluate the merits of the organizational form adopted by the government. The same factors that make the present task difficult for evaluators of AECL's performance also made the task insurmountable for AECL's political masters throughout the life of the project.

Measuring Management Performance in Complex Product Markets

The more complex the market in which the firm operates, the more difficult it is to measure the performance of the unit and the more difficult still to relate that performance to managerial behaviour. When success or failure is, at best, known in the long run, a modicum of ingenuity can rationalize virtually every temporary setback. Information asymmetries favour the managers over the owners and leave an open field for self-interested, opportunistic behaviour. In such markets the potential for the managerial market to reduce agency costs in private firms is sufficiently problematic. Does this mean that the public firm is just as good a choice for reducing agency costs? Wintrobe (1984) believes so. In his view, politicians have as much incentive at least to eliminate waste as do diversified shareholders of a private firm, and, possibly, more so. Simply put, Wintrobe argues that by eliminating waste, politicians free additional resources to deliver political services from which they can benefit personally through success in the political arena. He argues that the political market is just as efficient a mechanism as is the private market for controlling agency costs. This position is in dispute. The political market suffers from a double agency problem in that both politicians and managers may have opportunities to behave opportunistically at the expense of the ultimate owners – the taxpayers and the consumers of the commercial service supplied. Since individual politicians have short-time horizons, they may be free to realize immediate political rewards and postpone the consequences of their opportunistic behaviour to later generations of politicians. Evidently, when success or failure is unknowable, except in the long run, opportunities will abound for politicians to consume benefits in the present and transfer the political costs to the future.

Only when the product market is such that bureaucratic mechanisms of control are efficient is Wintrobe's argument at all convincing. For that reason, some authors – for instance, Borins and Boothman (1984) – emphasize the qualities of the product market when evaluating how effectively the political process can control the performance of managers of public-sector firms. The argument is simply that managers operating in a competitive market will not be able to earn a surplus to be allocated either to political uses or to managerial perks or inefficiencies. Borcherding made a similar point:

> As such they [Crown corporations] are attuned to the market as they are to politics, and, given competitive pressures, often differ little from counterpart private firms in their behaviour (Prichard [ed.], 1983, p. 131).

Alternatively, one can make the same point by stating that political control is potentially efficient when a firm's performance is easily monitored by auditing prices, balance sheets, and profit-and-loss statements, or, at the very least, productivity measures and costs. When ex ante opportunism and incompetency can impose only limited losses before ex post information reveals the situation to owners, the agency problem is evidently surmountable in virtually any form of organization. Eliminating the agency problem is equivalent to eliminating the need to consider the merits of one organizational form over another.

Managerial and Entrepreneurial Industries

For that reason it is important to distinguish "managerial" industries from "entrepreneurial" industries. Managerial industries are mature industries in which the market shares of the firms are relatively stable. The product or service is well along in its development cycle. Management of firms in such markets are usually process-oriented. In the Miles-Snow (1978) categorization, the managers of firms in managerial industries are described as "defenders"; they place great emphasis on process control over operational costs. The culture of the firm will favour careful monitoring of costs and the servicing of traditional customer groups. In such markets, the control and monitoring function is largely an automatic by-product of the market. Both success and failure are very soon evident to even casual observers.

An "entrepreneurial" market has been described as a market in which

> the inputs are perceptiveness, judgment, and timing rather than labour hours. High technology activities are, by this definition, entrepreneurial (McFetridge 1984, p. 22).

Organizations hoping to succeed in an entrepreneurial market must adopt a "prospector" culture. Experimentation, flexibility, a capacity for adjustment, a flare for the dramatic, a willingness to plunge in or to exit are all behaviours that Miles and Snow (1978) ascribe to "prospectors." Prospectors keep their rivals off guard and move rapidly to a dominant position in a market. The literature of business strategy is filled with case histories of firms demonstrating, and others failing to demonstrate, a prospector's capacity to initiate change in the market. This is the stuff of organizational planning that matches the structure and culture of the firm to the environment in which it chooses to operate.

The ability of the market for managers to reduce and control agency costs is clearly related to the type of product market – managerial or entrepreneurial – in which the firm is operating. Thus, except for convenience in exposition, it is inaccurate to compartmentalize these discussions. Public-sector managers have an added advantage over their private sector colleagues in that they may be able to use public funds to change the characteristics of the product market in which they operate. Baldwin (1984) and Weaver (1984) both argue that the managers of Crown corporations can, and do, follow strategies that build their own political constituencies. Similar observations are often made about civil servants. Thus public-sector managers may be able to consume resources to build effective lobbies whether or not, by so doing, they assist their alleged political masters to achieve their political objectives. They may successfully lobby for protection from competitors in order to supply political services to constituencies whose "voice" they have themselves cultivated – and possibly at the expense of the political options preferred by the politicians who happen to come to power.

The scope seems vast, in such circumstances, for waste in the delivery of political and commercial services. Managers in private firms might similarly turn to rent-seeking behaviour in order to generate opportunities for maintaining returns that simultaneously satisfy their shareholders and earn above-market returns for themselves. The waste associated with this form of behaviour has received a lot of attention elsewhere (Kreuger 1974). The question raised here is whether or not Crown corporations have an advantage in rent-seeking activity that encourages them to pursue it more actively than their private counterparts.

We conclude that the dimensions of the product market crucially affect the agency costs associated with different forms of corporate organization. The classifications of industry types are necessarily simplistic and hardly immutable. The automobile industry was a managerial industry until the energy crisis and Japanese entry upset the market-share equations by initiating dynamic industry changes. But even if the boundaries between industry types are fuzzy, no one would dispute that today the micro-computing industry is entrepreneurial whereas railway transportation is not.

In an entrepreneurial industry, the absence of a dominant industry leader, or a group of established firms invites "de novo" entry as well as entry by established firms in related industries. Once a firm establishes a significant market share, it begins to enjoy advantages that induce a "shake-out" as the industry matures. Firms that gain market shares reduce their costs when economies of scale and experience are present. More importantly, the initially successful firms usually gain consumer confidence, which may permit them to charge a premium price without losing sales. The latter factor is thought to be particularly decisive when the product being marketed is a consumer durable or a capital good. In those instances, buyers will be influenced by the potential resale value of their acquisition and by the availability of spare parts, service, and future improvements. Buyers of high-tech capital equipment will select the vendor they think is likely to endure to help cope with contingencies – the manufacturer the buyers believe who will survive and whose product will not become obsolete.

The Nuclear Industry Is Entrepreneurial

The nuclear industry displays many of the characteristics of a typical entrepreneurial industry. Utilities that buy a nuclear reactor ask for assurances that the vendor will be in business for the full 40-year horizon over which the reactor is expected to operate. They want someone to turn to if the system's performance is below standard. And if the decision of the utilities' manager is ever questioned, they want to be able to point to others who have made similar mistakes.

Thus the credibility of a producer in an entrepreneurial market is tied to his size. Buyers will pay a premium in order to deal with firms that they perceive to be more likely to survive. These considerations are well understood by proponents of government intervention in entrepreneurial industries. Indeed, it is in the alleged staying power of a government enterprise that some find the advantage of a public firm in the entrepreneurial sweepstakes. Many argue that it is unlikely that any private Canadian firm could hope to sustain itself in the international nuclear reactor market without a substantial guarantee by government that the enterprise will not be allowed to falter; but such commitments are only as valuable as they are credible to potential buyers. The conviction associated with a Canadian guarantee is compared by buyers to similar assurances by French, German, and U.S. vendors, each enjoying a unique level of government support.

Such considerations are well understood also by those managers of Crown corporations whose responsibility it is to commercialize new technologies in entrepreneurial industries. They know how important government backing is, and they resent any criticism of the program that may seem to potential buyers to be a weakening of resolve. Thus executives sometimes sound like Lyndon Johnson, for whom the war in Vietnam was winnable had it not been for the critics of U.S. policy at home who conveyed to the enemy that the U.S. would not stay the course. However petulant this sort of carping may seem, there is more than a grain of truth in the allegation that internal dissension and bickering over a program, where it becomes public, weakens the confidence of potential buyers, possibly at a critical time in the history of a new product's development. Thus, to some writers (Roderick White 1984, for example) what first appears to be a reason for government intervention in entrepreneurial industries turns out to be its Achilles heel. In our society, government enterprise must operate in a fish bowl, and few would want it otherwise.

Credibility problems also affect firms in the private sector. The Globe and Mail carried a story about Westinghouse being confident that the nuclear market will not disappear: "Westinghouse Expects Nuclear Power Revival" (October 9, 1984). They set out their intention to capture a giant share of what will be available over the next few years. In order to prepare for these new market opportunities, Westinghouse is joining in a $150-million venture with a Japanese firm to improve their light-water reactor designs. This staking-out of position comes after eight years without a single new order in the United States and despite the fact that numerous reactor orders have been cancelled even though construction work had been well on the way to completion.

The Merger Market

Shares in those public-sector services that are wholly owned by a government are not transferable. Competition for management control of a Crown corporation is therefore either diverted into the political realm or takes the form of interagency rivalry. The absence of a market for shares reduces the ability of the financial community to monitor the behaviour of the Crown corporation. In the private sector, financial analysts stand to gain or lose handsomely by monitoring the affairs of firms whose shares are publicly traded. In the public sector, the function of the financial market is assigned to government departments in which no one profits directly from an astute analysis. In addition to a lack of incentive for the government analyst is his or her reliance upon the managers of the Crown corporation for information. Nor can the government analyst's judgment be monitored by comparing it with the collective judgment of investors that emerges in the market price of the share.

Internal Financial Markets

In the private sector the internal financial market will often be as significant as the external market. Management teams like the one in control of Canadian General Electric are evaluated by shareholders, not simply for their acumen as operating managers. In the multidivisional firm, senior corporate officers operate an internal financial market and monitor the performance by the managers of operating divisions. The success of multidivisional firms is a measure of the ability of an internal financial market to reduce both transaction and agency costs. By this means, shareholders delegate the monitoring function to a small group of senior officers whom they hold responsible for the overall performance of the firm.

Roderick White (1984) argues that government has trouble effectively operating an internal financial market. In a study based on the Dash 8 aircraft decision, White criticized the government for failing "to manage a wholly-owned commercially-oriented corporation." White identified the government as a corporate head office and the Crown corporation as the strategic business unit at the divisional level. Integration of divisional and head office interests is achieved in various ways by private industry. The process involves trying to make the firm's structure suit its strategy and environment.

White pointed out that the Boards of Directors in government are supposed to perform the integrative function. Government appoints key deputy ministers to Boards in order to ensure that Crown corporations are aware of government policies and that the government knows what the firm is up to. This process seems to have collapsed miserably in the case of Canadian Crown corporations in entrepreneurial industries. White suggested that the holding companies, like the Canadian Development Corporation (CDC), may play the role of integrator. Why this should follow from organizational principles is uncertain. Presumably, White had in mind that CDC would be less easily enlisted in support of a project than would bureaucrats in government ministries and in central agencies. Possibly the higher profile of the CDC will give Cabinet members more reason to pause before committing themselves to program development.

White's criticisms focused on the financing decision; however, what he described as government failure in the Dash 8 case strikes this writer as a chastisement of government for acting governmentally. Governments must perforce have multiple and everchanging objectives; they cannot effectively operate an internal capital market and be guided by a single, overriding commercial objective. This explains why governments rarely say no to any plan until the last possible moment; they postpone making final decisions. In the meantime, interested groups vie to realign support in their favour within the government. This is an unavoidable characteristic of a democratic government; departments are likely to have as many clients and constituents as there are organized groups. More fundamentally, since the Cabinet's and the Prime Minister's time is the scarcest resource in government, senior government officers can only become involved in the "integrative" process through proxies.

Devising strategy demands a firm, clear, long-term commitment to a general theme and must be articulated by a small number of top executives who have the final say on key decisions. This enables "integration" to be built into divisional plans by the line manager's absorption of a firm's culture. This option seems a forlorn hope in the public sector; Crown corporations are not accurately idealized as divisions of government. To do that would be to displace responsibility for strategic commercial thinking outside the industry itself. That is the very criticism one hears about private conglomerates. Even the worst performing private conglomerates, however, do not place in key-decision roles "part-time" managers earning comparatively modest salaries having comparatively little at stake in the success of the firm and responsible for numerous other priorities.

The impediments to the successful growth of public firms are not to be sought in tinkering with divisional structures. Organizational change may help, but it does not solve the key problem which is the primacy of politics over fiscal responsibility and entrepreneurship. For example, the Canadair decision was certainly related to the timing of the Quebec referendum and the reluctance of the government to consider announcing a major withdrawal of federal support and a reduction of employment in Quebec. The Dash 8 decision may have been associated with the Canadair exercise in the sense that not to cancel Canadair while cancelling the more attractive Dash 8 project would have created a mine field of potential dangers for the federal government in Ontario.

The recent withdrawal of support from the Canadian Commercial Bank is another example of the primacy of political impressions over economic realities. On commercial grounds the Bank should have been wound up and not supported when its problems first came to light. Every regulator involved would well have understood that a recovery was virtually impossible because "smart money" would withdraw its deposits upon news of the government bail-out; politically, however, the government could not be seen to be indifferent to a regional bank. The provincial government, among other groups, would have had a field day with that. How much better, it seemed, to appear to make every effort to keep the Bank afloat and then pull the plug only after it became crystal clear that money alone was not enough to save the institution. Wise politics, it was surely thought, for civil servants not to embarrass their political bosses and, if possible, to sugarcoat the process; some may have even actually believed they were saving the Bank. Though this latter example is not from the world of entrepreneurial organizations, it does illustrate the cost of allowing politics to rule in all circumstances. How to separate politics from governmental functions like bank regulation is another matter. Heads of the Bank of Canada who are too independent of the politicians do not last long in Canada, and the office of the Inspector General of Banks is a civil service position presently staffed by a career civil servant.

The integration of entrepreneurial organizations into a massive governmental system may simply not be feasible. One reason for failure is that government is not a single massive organization peopled by persons all driving in common towards a well articulated goal. It is more like an octopus whose arms are all wandering in an uncoordinated fashion, often at cross purposes and with conflicting goals. Somehow the behemoth makes some progress in one direction or another. A Crown corporation was clearly intended, in C.D. Howe's mind, to be apart from government so that it might be free of the everyday pressures of political life that is the stuff of life for civil servants within government. But the C.D. Howe model may not work. If the Crown corporation is dependent upon government for its finance, the public firm will be tied to the apron strings of the politicians as surely as if it were a bureau. It seems unlikely that mere shuffles in its reporting lines or its budgeting procedures, will make Crown corporations effective competitors in entrepreneurial markets.

The limitations of the government as banker is more relevant to the CANDU than the Dash 8 project. The former is so long-term that successive governments have become virtual captives of the program.

Efficiency of the Political Process

The final point on our list of influences on the organizational considerations affecting the comparative performance of a public firm is the efficiency with which the political marketplace brings public preferences to bear on politicians and civil servants. A vast public-choice literature examines this issue, only one aspect of which seems especially useful for an analysis of the nuclear reactor industry and that is the extraordinary degree to which prestige exerts itself on politicians. The prestige issue is further exacerbated by the longevity of the nuclear reactor development process. Allison (1971) noted that national prestige ranks high in the motives of politicians, and prestige often develops in proportion to sunk costs. Massive "sunk costs" in the CANDU program combined with high technological achievements make CANDU a package of prestige that politicians would disassociate from only at their peril. In France, the loss of prestige demonstrated by accepting U.S. light-water technology was compensated for by massive investments in the pursuit of the fast-breeder reactor (see Bupp 1980; Bugler 1977*a*; Collingridge 1984*a*; DeLeon 1976, 1980; Fagnani and Moatti 1984). Considering the doubts that many have about the economic feasibility of the fast breeder, it may be that the French fast breeder ought to be a charge against the light-water program, being the political caution money paid to make possible the French shift to U.S. technology. The United Kingdom has not yet managed to extricate itself from the dominance of prestige over commerce (Collingridge 1984*b*; Burn 1978; Cook 1969), but the Sizewell inquiry (Pearce 1982*a*,*b*) will likely lead the British to turn to U.S. technology just as the French and Japanese have done before them.

There is quite widespread agreement that "political" considerations affect the nuclear power market. These usually "protectionist" sentiments will affect the nuclear options available to a Canadian venturer. It is reasonably predictable that because of the political impetus, world capacity will be overexpanded and profit margins thin. Private investors can enter these prestige fields only if they can count on protection at home and/or on subsidies for sales abroad. This is exactly what has occurred in the nuclear reactor industry, just as in steel, tankers, and petrochemicals.

The "political-decision" framework is useful for many purposes, but it detracts from the objective of this study. Here, the commitment to Canadian prestige invested in the CANDU project is not being questioned per se. It is the role of AECL as a vehicle for developing the CANDU. The counterfactual hypothesis is simply that Canada's nationalistic emotions might have been expressed through financing research and development in private industrial organizations. The latter policy was followed in the United States and Germany, whereas Canada, the United Kingdom, and France adopted a more direct instrument of intervention.

We have examined the factors that may mitigate the higher costs otherwise inherent in a Crown corporation. Few arguments seem to have any merit for the special case of nuclear reactor development. It is difficult to monitor the managers of an R&D firm selling into an entrepreneurial industry, especially to ensure that management salaries will be subject to government guidelines and that equity participation by managers will not be feasible. The long duration of the development process creates more dangers. Politicians can shift the political cost of present benefits to future politicians. The absence of a market in which to trade the shares of the corporation not only negates the market in which management teams compete, it also makes the valuation of the firm's prospects an internal exercise that is untested by independent valuations. But the government is unable to overcome this weakness through establishing an efficient internal financial market. Political prestige is so firmly attached to the pride associated with high-tech development that politicians are at the mercy of the Crown corporation.

In short, there are few redeeming features to justify the Crown corporation, except possibly the savings to be gained from combining a political objective with a commercial one. In the next section, that question will be addressed.

Section B: Political Considerations

What sort of political rather than commercial objectives might offset the relative inefficiency of the public firm in its commercial role?

Public vs. Private Influences in Foreign Nuclear Reactor Development Programs

One way to explore this question is to examine why, in some countries, government intervention in the nuclear industry has not been channelled through a public corporation. In the United States, Germany, and Japan, governments allowed the nuclear reactor business to be developed by private companies. These three governments subsidized research and development proportionally as much as or more than the Canadian government. So alternative instruments for delivering public policy to achieve similar if not identical aims certainly do exist. It is not, therefore, sufficient merely to list public objectives to conclude that a Crown corporation is an efficient means of achieving them. Before a Crown corporation deserves to be designated a potentially efficient mechanism, the efficiency of producing public and commercial services jointly ought to be demonstrated.

Until recently, the apparent success of the U.S. and German programs gave many writers grounds for favouring the "private" route. Burn (1978), on the basis of such international comparisons, argued exactly that way. He attributed the failure of the British, as compared with the U.S. nuclear program to the failures of a public firm. And yet, more recently, nuclear power enthusiasts have been able to point to the apparent success of the French nuclear program. More recently still, the French program is seen to have caused a huge overcapacity in facilities to produce nuclear reactors and still more overcapacity in French generating stations (Collingridge 1984*a*,*b*). Even before its recent difficulties, however, the French program would have been deemed successful only by those who restricted themselves to the light-water reactor program. When one examines the enormous sums committed by the French to other nuclear programs, its total effort does not score a high mark. Evidently, simple comparisons of reactor industries in different countries sheds little light on the question under investigation here.

One might be able to identify a government's motive for a public corporation by examining why some countries chose to develop the nuclear industry within a public corporation while others opted to use one or more private firms. In France, Britain, and Canada most electric utilities were already in the public sector. In the United states and Germany, private and public utilities co-existed. This correlation may have been accidental, or it may simply reflect some prior ideological commitments to a particular size of public utility. It may, however, reflect a public utility's preference for dealing with a single supplier that can be influenced more effectively through political voice than a private monopolist enjoying large government subsidies. This seems to have been one of the factors that influenced Ontario Hydro at a crucial time in the development of the Canadian industry.

How and Why the Canadian Nuclear Program Became a Public Project

In Canada, the association between the Atomic Energy of Canada Limited and Ontario Hydro dates back to 1952 when AECL was founded. Given the better bargaining position of Ontario Hydro in this partnership, it is not surprising that the Canadian nuclear industry is a public undertaking. From this perspective the nuclear industry is simply an extension of Ontario Hydro, and to find out why it is public we need to examine, first, why Ontario Hydro is in the public sector and why Ontario Hydro asserted its influence in favour of the public rather than private option. The first question has received much publicity elsewhere. Recently, Baldwin (1984) offered a new interpretation of the data advancing a bold new reason for Crown corporations in certain industries. According to Baldwin, firms having a large capital investment in immovable facilities with no alternative uses are susceptible to opportunistic behaviour by politicians. In the short run, politicians can respond to consumer pressure by imposing low prices without withdrawing service. This process is parallel to the way rent control is imposed, despite the knowledge that, in the long run, rent control damages the housing stock and forces the government to supply public housing. This mechanism, although very inefficient, may still be the best means by which politicians can respond to tenant associations' demands for rent control. Baldwin demonstrates that, for constitutional reasons in the U.S., utility industry rate-regulators were required to set rates that would allow a reasonable rate of return. In Canada there was no such legal protection provided against the expropriation of private property achieved by setting maximum prices so low that a firm could not recover its capital cost. Once private investors are dissuaded by low returns, a public firm takes over the responsibility. In that sense, the public firm, writes Baldwin, may be a social mechanism that has evolved as a means of responding to the opportunism of politicians. Ironically, one of the burrs under the U.S. nuclear industry is the political sensitivity of rate regulators. They are interpreting the regulatory rules as not allowing new nuclear generating stations, especially those that are not to reach competition and enter into operation, into the rate base. Firms are having extraordinary difficulty financing these projects because there is more than a little doubt about whether the regulators will allow rate increases of 50, 60, or 70 per cent. These are the sorts of increases that standard rate-of-return formulas call for when the rate base is increased by the book value of a nuclear power station, including the accumulated cost of capital during the period of construction (Cook 1985).

As attractive as Baldwin's thesis may be in explaining the domination of Canadian electrical utility markets by public corporations, it fails to fit the specific case of the emergence of AECL. One can think of a number of cases of ex post opportunism that would have dissuaded a private firm from taking any initiative here, at least until the government had set out a policy for funding private research and development. Without government support, the private firm would have been forced to compete with foreign nuclear reactor developers who are supported by government subsidies. Even some sort of federal guarantee of the Canadian market would be an unconvincing carrot. Knowing that provincial utilities are the only customers, a private developer would have every reason to fear that political opportunism would force him to reduce his price to the level of the foreign competitor. Otherwise the firm might expect the government to remove protection from foreign producers, or it might be expropriated by the provincial government at book value. Either way, the fear of political opportunism causes any reward for risk taking to be reduced to an unreasonable level. If the project fails, the investor loses all, notwithstanding the public subsidy. If the research and development succeeds, the investor is unlikely to be allowed to earn the sorts of high returns that a risk-prone project such as this would usually command.

The above scenario offers one possible explanation as to why a private firm might hesitate to invest heavily in nuclear reactor development in a small domestic market with only a handful of potential buyers, especially when those buyers are in the public sector. Canadian experience does not, however, seem to conform to the opportunism model. Instead, government has actively discouraged private-sector development. There seems to be two reasons for this. First, the Canadian firms potentially capable of undertaking the research and engineering work at the outset of the program were both subsidiaries of U.S. firms. The parent companies – General Electric and Westinghouse – were each pursuing other and competing nuclear power options. Second, Ontario Hydro maintained its long-standing policy of encouraging multiple sources of supply.

The Influence of Canadian Nationalism

It was not always true that nationalism caused the government to discourage the participation of Canadian subsidiaries of foreign firms. In 1954, the contract to build the NPD reactor was let to Canadian General Electric. (For a list of Canadian reactors see Table 3-1.) Sims (1979) reports that one important factor favouring CGE was its parent company's participation in the U.S. nuclear power program. This attitude did not last. The commercial exploitation of nuclear reactor technology had not yet commenced in 1954. Canadian authorities may have perceived the U.S. connection to be a means of inexpensively accessing foreign technology. Just five years later, however, when the Douglas Point reactor was being designed, AECL likely perceived itself to be in a commercial race with Westinghouse and General Electric.

Certainly nationalism influenced decision makers on numerous occasions when private-sector involvement in the program might have been maintained or increased. But if the Canadian government believed it was in a race with foreign competitors for lucrative sales in foreign markets, it can hardly be blamed for not wishing to risk sharing its technology with a competitor's subsidiary. This brings us around to the crucial issue. Was the Canadian government motivated solely by commercial profit opportunities or did it have other aspirations?

Determining AECL's Mission – Was it Intended for AECL to Become a Government Research Laboratory or a Commercial Organization?

As is so often the case, all the participants in the early days of AECL had mixed motives. Sims (1979) and Eggleston (1965) reviewed the early history of AECL. What follows relies principally on those secondary sources. Based on that literature and a handful of interviews with some pioneers in the field, it is safely concluded that many persons in the scientific establishment looked to commercial opportunities as a means of ensuring that both research facilities and opportunities would continue to be available to them.

Before AECL was founded, a commercial products division at Eldorado Mining and Refining Limited – a Crown corporation – was engaged in processing radium and radium products. That group was transferred to AECL in 1952. Eggleston stated that

> It was recognized from the beginning that since the market in Canada for isotopes would be limited, it would require an export market and large volumes to reduce costs and offer a first-rate service to Canadian users (p. 274).

Sims reported that as early as 1947 when the NRX reactor went into service, Dr. MacKenzie, later to become the first President of AECL, was

> worried by the large size of the Chalk River establishment, which was only being used for nuclear research purposes ... a new reactor primarily dedicated to plutonium production would provide a strong commercial justification for Chalk River (p. 40).

Financial concerns were aggravated by the expectation that the working life of a reactor might only extend five years.

Table 3-1

Canada's Domestic Nuclear Power Program

	Capacity (MWe)	Date of order	Date of operation (actual or scheduled)
Reactor or station:			
1) NPD	22	1955	1962
2) Douglas Point	200	1959	1966
3) Pickering A 1, 2	4 x 515	1964	1971
3, 4		1967	1972-73
4) Bruce A	4 x 746	1969	1977-79
5) Gentilly II	637	1973	1982
6) Point Lepreau	630	1974	1982
7) Pickering B	4 x 516	1974	1983-84
8) Bruce B	4 x 756	1975	1983-87
9) Darlington	4 x 881	1978	originally 1984-87, but now 1988-90
Total (3-9)	14,923		
Total (3-8)	11,400		

SOURCE Canada, Department of Energy, Mines and Resources, *Nuclear Industry Review: Problems and Prospects, 1981-2000* (Ottawa: Supply and Services Canada, 1982), p. 4.

The NRX was planned in 1944 to cost $10 million. It came on stream three years later in 1947, and its cost probably exceeded the budgeted amount. At that stage, then, the scientific community foresaw a need for significant and continuing expenditures to make nuclear reactors available for scientific research.

The NRU reactor project proceeded in 1950 on the basis of a contract to supply plutonium to the U.S. government. No wonder, then, that Sims reported as follows:

> the government fully expected that AECL could eventually become self-supporting from the sales of radio isotopes, mainly plutonium.

This hope vanished in 1962 when the United States failed to renew its contract for plutonium.

One of the major reasons for AECL having been created as a Crown corporation in 1952 and for separating it from the National Research Council (NRC) was the increasing commercial nature of its activities. But the responsibility for generating electricity was not in the initial mandate of AECL. The possibility of doing so was then in the air. Dr. W. B. Lewis completed a proposal for atomic power in August 1951. In 1953, C.D. Howe revealed for the House of Commons that

> the production of power is the concern of those who distribute power – organizations like the Hydro Electric Power Commission of Ontario (HEPCO – later to be renamed Ontario Hydro) or the major privately-owned power companies (Sims 1979, p. 99).

When AECL was first set up, Canada's chief planner was not thinking of taking it into the power-generating field. In 1954, a study team headed by a HEPCO engineer was set up in which B.C. Electric, Shawinigan Water and Power Co., Manitoba Hydro, Canadian Brazilian Services, Montreal Engineering, and Babcock & Wilcox participated. (In an interview with a senior CGE executive I was advised that CGE also participated in this task force, but Sims did not report that.) AECL reported that

> contracting firms will be responsible for design and construction and for mechanical performance (quoted by Sims 1979, p. 10).

With the design work complete, tenders were let, and CGE was awarded the contract.

In 1956 the government estimated that its expenditures in the five years to follow would be $36, $30, $20, $13 and $15 million, respectively; AECL actually spent $3, $25, $29, $31 and $38 million (Sims 1979, p. 106). Evidently, in 1956 the government did not foresee itself at the brink of a major financial commitment, although it was conscious that its investments were more than a little risky.

> ... no one could say at this time which type of power reactors would prove to be the most economic (W. J. Bennett 1956, as quoted by Sims 1979, p. 112).

Only after 1959 did the government commit itself to gambling a large amount of money on the chance of an economic opportunity. Until then, it had hoped to contain the costs of scientific experimentation through modest expenditures that were fully expected to earn both income and prestige. In 1960 the CANDU remained a doubtful proposition. By now, however, the government had sunk $81 million into the Douglas Point reactor project. Hydro Ontario was expected to buy the plant once it was fully operational; however, the Government of Canada financed the project and shouldered all the risks.

Sims listed the multiple political motives at play. First, the reaction to the Conservatives' cancellation of the Avro Arrow project warned the Liberal government of the political price to be paid for the cancellation of a scientific project. Second, the uranium mining industry was then largely located in the Prime Minister's home riding of Elliot Lake, and it was being threatened by a U.S. embargo on importing uranium. Finally, Ontario Hydro required new generating facilities quickly, and it became an avid fan of the CANDU system.

C.D. Howe was no longer the politician in charge. In 1957 he was replaced by Gordon Churchill as the Minister in charge of atomic power. Howe is well-known for having believed that Crown corporations ought to be, first and foremost, commercial corporations. He and the President of AECL at the time agreed that the private sector should be the developer of nuclear power. Bennett was a

> strong advocate of private sector involvement in the development of nuclear power (Sims 1979, p. 14).

This changed altogether in 1958 with the appointment of Lorne Gray. As early as 1956, Gray had declared his hostility to Canadian engineering companies in the following terms:

> there are no experienced development departments in Canadian engineering manufacturing companies (Sims 1979, p. 115).

He blamed this on the branch-plant nature of the Canadian industry. At the time, CGE's performance in constructing the experimental NPD reactor was being criticized. But a private contractor was probably out of the question by then because AECL had already built up a design team to work on the Douglas Point reactor. As mentioned above, Ontario Hydro preferred to have AECL supply the nuclear reactor and certainly took no steps to resist Lorne Gray.

Strategic long-term thinking did not cause the shift away from private to public development of the CANDU system. If the federal government was, at that time, thinking of selling CANDU abroad in competition with U.S., British, French, and later German and Swedish reactors, it gave no indication of that. It built an organizational structure that was appropriate for delivering under a project mandate; see Sayles and Chandler (1971). The AECL need not have had a marketing strategy if it was to remain a partner with a provincial Crown corporation that was looking solely to supplying its internal requirements for generating capacity.

Atomic Energy of Canada focused on domestic developments. It participated in the design work for a reactor built in India, but the contract was between governments and was part of Canada's aid for India. Canadian General Electric, frozen out of the domestic market, turned to the foreign market with limited success. In 1964 it sold a reactor to Pakistan on a fixed-price contract, and it earned a profit. After that it failed to make any more sales. The CGE executive at the head of their nuclear program at the time said in an interview that CGE was a front runner to sell a CANDU reactor in Argentina but that the government was unwilling to assure export-financing guarantees on two projects simultaneously. The company asked to be authorized to offer the guarantee of financing to both Argentina and Finland and to accept only the first bid.

Why the government would not have agreed to an arrangement like the one suggested by CGE is difficult to imagine. Was AECL worried about a domestic competitor? Argentina accepted an offer from Seimens for a heavy-water design reactor largely because of the better financial terms offered.

In 1964, the same year that it won the Pakistan contract, CGE was prepared to bid, on a fixed-price basis, on the design and construction of Pickering. Ontario Hydro and AECL made it quite clear to CGE that it would not accept their bid under any circumstances.

Since to prepare a bid costs several hundred thousand dollars, CGE did not bid, and the occasion virtually marked the end of major private-sector participation in the business of designing nuclear reactors. CGE departed from the industry as an integrated designer, marketer and builder of nuclear reactors in 1968.

Atomic Energy of Canada absorbed many CGE marketing people, and it was authorized by the government to market nuclear reactors abroad. The significance of the export drive to AECL is indicated by the personal involvement of Lorne Gray, the President. Sims (1979, p. 133) reported that he involved "himself in all aspects of the marketing program." The export market was fiercely contested (see Table 3-2 for a list of export sales). The vice president of marketing at AECL remarked that "there were almost as many bidders as buyers" (Sims 1979, p. 135). Gray did not underestimate the importance of export sales. Although, until 1975, domestic demand looked to be sufficient to maintain a healthy level of activity for CANDU manufacturing, Gray acknowledged that

> if you do not get any business it will certainly indicate there is something wrong with AECL. We are putting our reputation on the line (as quoted by Sims 1979, p. 136).

Speaking later, in 1977, he admitted that we

> were really concerned about the future of the Canadian nuclear power program if we did not get something (as quoted by Sims 1979, p. 136).

Sims made much of J. S. Foster's remarks in 1975. Foster, who had taken over from Gray as the head of AECL, stated:

> They do not, however, give a true picture of what is basically important in AECL's operation. AECL's main role must continue to be the development of methods of applying nuclear energy for the increasing benefit of mankind in general and Canadians in particular.... It has been necessary to take on major commercial responsibilities such as the production of heavy water and the export of nuclear power plants to maintain a healthy Canadian program but these are *incidental to AECL's main role* (as quoted by Sims 1979, with emphasis added, p. 259).

Sims believed that Foster was admitting that AECL was a research organization that approached commercialization in an off-hand manner. This may have been the case, but it is just as convincing to read the above quote in the context of an organization that realized it had failed to fulfill its mandate. Embattled over a paltry number of loss leader sales abroad, frustrated by lack of acceptance in the United Kingdom, Japan, and Italy, and embarrassed by a fiasco in the production of heavy water, who would not seek refuge in the thought that these were secondary concerns? And even if AECL visualized itself as a research organization for research sake, is this what the government had in mind? Sims faulted AECL for never having taken its commercial mandate seriously enough. It

Table 3-2

Summary of Export Sales, by Country

	Date of order	Date of operation	Type
India	1956	1960	NRX-type research reactor (CIRCUS)
	1963	1972	200-MWe power reactor (RAPP 1)
Pakistan	1964	1970	125-MWe power reactor (KANUPP)
India	1967	1981	200-MWe power reactor (RAPP 2)
Taiwan	1969	1971	NRX-type research reactor
Argentina	1974		600-MWe power reactor (CORDOBA)
Korea	1976		629-MWe power reactor (WOLSUNG)
Roumania	1979		629-MWe power reactor (CERNAVODA – 1)
	1981		(CERNAVODA – 2)

SOURCE Canada, Department of Energy, Mines and Resources, *Nuclear Industry Review: Problems and Prospects, 1981-2000* (1982), p. 4.

is possible to read the same data as indicating that AECL did indeed take its commercial mandate seriously, it merely failed to make a go of it.

The Growing Role for Commercial Exploitation of CANDU

The premise motivating this section is that a Crown corporation could be an efficient instrument for delivering government policy, if simultaneously the government has other non-commercial objectives. At the outset of the nuclear reactor development program, commercial opportunities were clearly secondary. Such opportunities were thought to be a simple and convenient means of financing a growing research effort. The research effort was initially a matter of prestige and one of appreciation that the education and training associated with atomic projects would help to train personnel for the future. A minor effort to exploit commercial opportunities was launched. The isotope business seemed to develop of its own accord, and later the nuclear reactor market presented itself in the form of Ontario Hydro demand. Atomic Energy of Canada have expected that at the then predicted rate of growth of world reactor demand, buyers would come to its door without solicitation.

The initial focus of AECL and its government sponsor was research, but its mandate included commercial activities in order to finance that research. Without the latter expectation, there would have been no reason for transferring AECL out of the National Research Council. At the time, there was widespread optimism about the future commercial potential for nuclear energy. But events controlled AECL rather than the reverse. In time, the political awkwardness over curtailing prestigious scientific projects and over the participation of U.S. branch plants, combined with bureaucratic and technical arrogance towards commercial endeavours, oriented AECL. It was surely no accident that Lorne Gray became president of AECL at that crucial time. His views and attitudes were on record. Some political process was surely at work in bringing to the head of AECL a president who welcomed direct government intervention. In that sense, one cannot distinguish AECL's influence on the government from the reverse.

At the outset of the program there was no opportunism involved. All sides seem to have been well informed and aware of the process in which they were engaged. The effect was to eliminate CGE as a contender in CANDU markets and to focus on the partnership with Ontario Hydro. The government's failure to support simultaneously CGE's bids in both Argentina and Finland suggests that it was satisfied with its own vehicle for developing the technology.

After 1968, the government's expectations about AECL changed fundamentally. The increasing charges to the federal treasury were not being counterbalanced by commercial opportunities. All benefits from the program, measured in terms of employment or installed nuclear-generating capacity had accrued to Ontario alone. The federal government needed some foreign exports, if only to justify its role in a program that was benefiting the then richest province in Canada. The heavy-water fiascos can be explained by political sensitivities that sought to reallocate some of the benefits of the program to the Maritimes and Quebec. After 1968, then, the political interests of the Canadian government were tied almost exclusively to the commercial success of the CANDU reactor in world markets. Not only would this justify the use of federal subsidies to voters and governments outside Ontario, it would stimulate demand for heavy water from the Maritimes and engineering services domiciled in Quebec. Ontario had by this time moved to meet most of its own requirements internally, apart only from research. Atomic Energy of Canada was becoming the Canadian developer of CANDU abroad, assuming somewhat the same role that had been assigned to CGE just a few years earlier.

Two anonymous referees point out that the Canadian government revealed second thoughts about an aggressive commitment to commercializing nuclear reactors through sales abroad. This is evidenced by Canada, among countries trying to export nuclear reactors and uranium, having taken a leadership position in seeking safeguards from buyers aimed at ensuring that Canadian nuclear reactors and uranium would not be put to military uses (see "Canada, EMR 1981*b*, p. 333; Noble 1978; Legault 1976; Keeley 1980; Hunt 1977). But political considerations that may have hampered Canada's marketing efforts did not materialize until after India exploded a nuclear device in 1974. The safeguards issue therefore has no bearing on AECL policies prior to 1974. Moreover, a central thesis of this study is that AECL failed to sell CANDU reactors in developed countries, especially in the United States and West Germany. In these countries, as also in Great Britain and Japan, the safeguards issue would not have had any influence on CANDU sales.

It is concluded, therefore, that, at least from 1970 on, the federal government valued the commercial success of AECL, especially in world markets, not just for the financial advantage but also for political advantage. No joint or competing political services need have impeded AECL from fulfilling its commercial mandate. When domestic political considerations played a role, as in the construction of heavy-water facilities in Nova Scotia and Quebec, the federal government provided the extra financing. Atomic Energy of Canada was never asked to cross-subsidize any group or region out of its own revenues.

4 A Framework for Organizational Analysis

As outlined in Chapter 2, organizational theory is not developed to the point where it offers an adequate framework for making a definitive choice between a public and private firm as an instrument of public policy. It does indicate that in the absence of non-commercial public objectives for the firm, a privately-owned firm is to be preferred. The advantage of a private over a public firm is difficult to quantify, however. It may be insignificant, in which case even minor political goods could be delivered at reasonable cost through a public corporation.

Until theory is better established, it is natural to evaluate the performance of a public corporation by comparing its conduct and performance with best managerial practice.

Business Strategy

The business strategy literature collects examples of managerial practices and strategies that correlate with success. Though not definitive, these correlates do enter the thinking about strategic planning in most major private corporations. From this perspective, it is interesting to ask how AECL's management performed compared with the best standards of private-sector management.

Not all organization theorists agree that management has the capacity to pro-actively influence the organizational structure, conduct, and performance of the firm. These groups of theorists, conveniently grouped together here under the title of "environmental-dominance theorists," believe that the organization's structure and strategy conform to certain functional prerequisites in some predetermined fashion.

The viewpoint adopted here is that the environment, though highly influential, allows managers to operate with a large measure of free will. In the "management strategy" model adopted here, top decision makers in the organization determine its objectives and align the organization towards attainment of those objectives.

This doctrinal distinction between the "environment" and "strategy" theorists is peripheral to the purpose of this study. The strategic model is adopted because it sets out what contributes to effective management. The objective is not to blame ex post the players who followed what seemed, ex ante, to be an optimal strategy; the objective is to learn from past experience and to contribute to a sounder understanding of the path that a government sets for itself when it decides to become the main sponsor of risk-prone and newly developing industries.

Nor is the "business strategy" literature so advanced that it enables the analyst to make definitive forecasts of what tends to success and what is doomed to failure. It is difficult, for instance, to explain why Xerox – renowned for technological innovation – should have allowed so many of the key technological breakthroughs in the microcomputer industry to be exploited by Apple and others, though they were developed in Xerox laboratories. Nor is it evident why IBM, a late starter in the microcomputer field and a firm widely alleged to be inflexible, should have emerged almost overnight as the main challenger to Apple. Countless others, including major computer producers and well-managed firms like Texas Instruments, Hewlett-Packard, and Digital Equipment (DEC), tried and failed.

Strategic Management

Though strategic choice is the domain of the chief executive officer (CEO) and senior corporate management, their choices will be constrained by the various constituencies upon which the performance of the organization depends. Broadly speaking, Donaldson and Lorsch (1983) identified three key constituencies: the capital market, the organization and the product market.

Capital Markets

The capital market is the source of external finance, which includes shareholders as well as sources of debt finance. Donaldson and Lorsch documented that firms seek in every way to be independent of those external suppliers of finance. Senior management's responsibility to this constituency is internalized. Major firms make an intense effort to operate an internal financial market. Most firms within the sample studied by Donaldson and Lorsch gear the growth of a division's assets to the divisional returns retained by the firm.

Top managers consistently identify external financial sources as fickle and seek market strategies that permit internal financing of investments that are thought to be especially risky or to have long gestation periods. It is from this notion that the "growth/market-share" matrix, popularized by the Boston Consulting Group, is well received by corporate leaders. The matrix combines two fundamental themes – portfolio diversification as a means of risk reduction with the "product-cycle" model. The product-cycle scheme is supplemented by the "learning or experience effect." Together, these effects lead innovators to rush expansion and growth in order to pre-empt a substantial market share. Consequently, investment at the early stage of the product cycle must be large and possibly irreversible. For management to retain the allegiance of its owners and creditors, and to enable it to manoeuvre strategically, it is prescribed that the organization should adopt a product mix at various stages along the product cycle. This outcome flows from a preference for internal over external sources of finance.

The drive for freedom from "capital-market dominance" is partly explained by the insider's attitude towards risk. Donaldson and Lorsch report that explicit risk analyses are absent from the formal planning processes of these firms. They report that "senior executives believe that risk can be modified by managerial wisdom and skill." Senior executives distrust the market outsider's judgment of risk and opportunity, and they expect that a successful long-run track record will satisfy the financial constituency. Many corporate managers are reported to have consciously diversified outside the traditional strength of their firm in order to attain greater stability for "strategic" corporate manoeuvre.

Product Markets

The product-market constituency imposes its discipline primarily through the actions of a small number of key competitors. "Share of the market" or "rank in the industry" are measures that management uses to evaluate success even when those measures cannot readily be related to profitability through economies of scale or other advantages associated with scale. Buzzell, Gale, and Sultan (1975) reported that in industrial-goods markets, the share of the market is a particularly critical measure of success. This is still more the case when buyers are few and purchases are infrequent – circumstances that clearly describe the nuclear reactor market.

The Organization's Constituency

Finally, the organization constituency constrains senior management's freedom because its stability depends upon retaining its highly trained professionals and managers. The lower one is in the corporate hierarchy, the greater his or her mobility. Longer tenure increases one's value to the firm while decreasing one's market value to other firms, because "firm-specific" skills and knowledge increase in relation to general qualifications. Senior management, therefore, seeks to ensure growth in order to maintain opportunities for promotion or, otherwise, to build loyalty to the organization.

Research departments are especially difficult to manage. The literature is full of examples of a research department's culture deviating from a company's norms. Researchers are reported to be "prima donnas, like members of a university faculty; the timing and usefulness of their output is uncertain" (Jauch 1983, p. 20).

This observation is, of course, particularly relevant to AECL since until 1978 it was said to have resembled an R&D division of a major firm. As reported above, from its earliest years commercial opportunities were pursued not for their own sake but as a means of financing further research on nuclear physics and engineering. Sims reported that Dr. MacKenzie "felt strongly that AECL should have a first president from the research tradition" (1979, p. 40).

Motivating Managers

In the private sector, senior managers are themselves virtually independent of financial pressure. Once they reach the pinnacle of the organization, they are wealthy men. Their wealth, however, is underdiversified. A disproportionate share of their wealth is tied up in the equity of their own firms; for that reason, even if senior managers are wealthy, their behaviour is affected by executive compensation plans. Recently, Jensen and Zimmerman ([eds.], 1985) reported findings that support the conclusion that "executive compensation plans help align managers' and shareholders' interests." The papers they reported on document that

1) executive compensation is positively related to share price performance;

2) poor firm performance is associated with increased executive turnover;

3) managers choose accounting accruals in ways that increase the value of their bonus awards;

4) the adoption of new short- and long-term executive compensation plans and golden parachutes are associated with positive share price reactions;

5) managers are less likely to make merger bids that lower their stock prices when they hold more stock in their firm.

For the 12 "Fortune 500" companies studied by Donaldson and Lorsch (1983), the average age of the 12 CEOs was 60. The average compensation for 1978 was $326,000, and all of them held a considerable amount of wealth in the form of shares of their corporation. This amount varied from $300,000 to $500 million. Non-CEO corporate managers in that sample of firms were just slightly behind the CEOs. Their mean age was 56; they had served for 26 years with the same company; their mean salary was $204,000; and they owned shares in their firm worth $780,000. Share ownership ranged from a low of $90,000 to a high of $5.4 million.

These data for the 12 Fortune 500 companies conform to similar measures for the full population of the 500 companies. This suggests that firm-specific knowledge is of such importance to senior corporate managers that only rarely are they recruited from outside the firm. Senior corporate managers are creatures of the cultures of the firms that spawn them. Unfortunately, Donaldson and Lorsch do not explore the functional specialties that the senior managers bring with them, as this might tell us something about the fields that incubate the best strategists. At AECL the executives' interests are not tied to the firm in the same fashion as described above. Eleven AECL executive officers were paid an aggregate of $955,167 in 1982 – up from $746,700 in 1981. This level of remuneration hardly compares with the $200,000 in U.S. dollars earned in 1978 by individuals in comparable positions in the U.S. Fortune 500 companies. It is superfluous to mention that senior executives hold no equity in AECL.

Senior managers are constrained to act on behalf of their various constituencies by their own equity position in the firm, their roots in the culture of the firm, and the selection process that brings them to the top. The threat of a merger or a proxy fight seems to provide, at most, infrequent disciplining of the managers of major firms. It is possible that the potential for transferring control away from an incumbent managerial group may be a spur to performance, but Donaldson and Lorsch believe senior managers are governed by other motives. Similarly, the market for senior managers is thin; thus, firms seem to ensure that once they are near the top, those managers are sufficiently well rewarded to retain their allegiance. Some have argued that shareholders are protected from management shirking by a competitive market for senior managers. Donaldson and Lorsch's findings suggested that the promotion systems used are so effective that management firing and hiring in the top echelons is extremely rare.

Donaldson and Lorsch also suggested that senior managers are strongly motivated to perform well because of peer pressure and because of the desire to retain independence in their own functions. The ability to balance constituent interests is lost when earnings falter.

By way of summary, then, we can characterize top management's job as one that creates some independence for strategy formulation and implementation. If they become beholden to one of the firm's key constituencies, senior managers may find that they cannot get the firm off on a siding even when they know that to continue on the present track is to court disaster. When this framework is applied to AECL, it appears that AECL's top management does not have the required independence to formulate and implement strategy. It is dominated by all three of its constituents: the capital market, in the form of the Government of Canada; the product market, in the form of its coventurer, Ontario Hydro, and its competitors, especially Westinghouse and Framatome; and its organization, largely comprising R&D-type personnel. In addition, AECL's senior managers are not paid salaries, nor are they offered incentive, commensurate with those of leaders with the same level of responsibility for formulating and implementing business strategy in comparable firms in the private sector.

AECL and the Capital Market

Federal Government Financial Support

The financial market for AECL is the Government of Canada. Politicians and government bureaucrats control the external funding available to the organization. External funding has been substantial. Table 4-1, from a study by Palda (1984), indicates the extent of just R&D support alone. Without the government's "purchases" of R&D services from AECL, its balance sheet would look bleak indeed. But this little bit of camouflage is useful, insofar as it provides some measure of performance on current operations. In addition, the government contributes to maintaining "prototype" reactor operations and has written off both the debt and interest associated with various reactor and heavy-water installations that are abject failures in both technical and commercial terms. Until the cancellation in March 1985 of heavy-water production in Nova Scotia, the government had funded the costs of producing and storing heavy water, which AECL had wished to discontinue for some time. With 10 years' requirements in storage and no markets on the horizon, the political influence that permitted a handful of jobs in a given riding to warrant, over many years, annual expenditures of

Table 4-1

Federal Government Expenditures to Support Nuclear Energy Research and Development, Canada, 1947-82 (Current and 1981 Dollars; Expenditures Funded by Appropriations)

	AECL R&D	AECB research	NRU reactor and Chalk River facilities	Total R&D support	
			($ Millions)	(Current $)	(1981 $)[‖]
1981-82	145.715	–	–	145.715	145.715
1980-81	123.119	–	–	123.119	136.660
1979-80	114.654	–	–	114.654	140.680
1978-79	119.120	–	–	119.120	161.230
1977-78	128.490*	–	–	128.490	184.865
1976-77	110.058†	–	–	110.058	169.295
1975-76	93.576	11.346	–	104.922	177.083
1974-75	85.921	10.375	–	96.296	179.871
1973-74	87.918	7.245	–	95.163	204.898
1972-73	78.206	7.896	–	86.102	202.335
1971-72	77.048	11.720	–	88.768	219.035
1970-71	68.942	7.100	–	76.088	193.768
1969-70	69.000	5.400	–	74.400	198.250
1968-69	68.600	3.959	–	71.195	198.041
1967-68	66.500	2.500	–	69.000	198.189
1966-67	57.983	2.000	–	59.983	178.721
1965-66	52.667	1.600	–	54.267	169.293
1964-65	45.158	1.250	–	46.408	149.491
1963-64	44.924‡	0.900	–13.761	32.063	105.757
1962-63	37.062	0.770	–	37.832	127.175
1961-62	33.933	0.700	–	34.633	118.144
1960-61	38.218	0.650	–	38.828	132.875
1959-60	29.408	0.650	1.098	31.156	107.973
1958-59	25.684	0.400	4.714	30.798	108.866
1957-58	21.131	0.400	8.863	30.394	108.929
1956-57	21.544	0.300	11.001	32.845	120.241
1955-56	18.626	0.300	12.554	32.886	124.840
1954-55	14.645	0.300	6.967	20.506	78.326
1953-54	12.360	0.300	4.009	16.669	41.131
1952-53	12.610	0.300	4.794§	17.704	68.579
1951-52	12.076	0.200	–	12.276	49.656
1950-51	7.177	0.150	–	7.327	32.990
1949-50	6.618	0.150	–	6.768	31.440
1948-49	5.747	0.143	–	5.890	28.327
1947-48	5.573	0.150	–	5.723	30.893
Total R&D support, 1947-82					4,683.396

* Excluding $87.571 – million budgetary expenditure covering write-off of Gentilly I debt.
† Excluding $85.491 – million budgetary expenditure resulting from forgiveness of interest on Gentilly I and Douglas Point reactors.
‡ Excluding $25.239 – million budgetary expenditure covering write-off of NRU reactor.
§ Non-cash item: Namely, value placed on assets of Chalk River Project on March 31, 1952, when AECL was created.
‖ GNE deflator (1971 = 100), fiscal years March 31, 1977 to March 31, 1982; 1981 index value estimated at 246.75.
SOURCE K. S. Palda, *Industrial Innovation: Its Place in the Public Policy Agenda* (Vancouver: The Fraser Institute, 1984), pp. 105-106.

hundreds of millions of dollars (mostly to pay for energy inputs that were themselves being subsidized) is to be admired, even if the waste is to be deplored. In 1982 alone, the Government of Canada advanced about $284 million to Atomic Energy of Canada Limited with no realistic expectation of ever seeing a financial return on those funds. Of the total, $138 million was to carry old commitments like the maintenance of Gentilly I and the Douglas Point reactor, as well as the continued production of heavy water. This was in addition to the $750 million written off by the government in 1971 for heavy-water plant construction. Palda estimated that, in total, the government had advanced about $6 billion in 1981 dollars as of 1982, two-thirds of which went for R&D and the rest to write off prototype reactors and heavy-water plants. Palda's estimates intentionally overlooked the opportunity costs of the funds advanced. Using a 7.5 per cent real rate of return as the opportunity costs of those advances, the current cost of Canada's investment is sizeable indeed. (Having amounted to over $14.2 billion in 1981 dollars up until 1981 for R&D support alone.)

In spite of those sizeable figures, the full cost to the federal government has been understated. Outstanding loans to provincial utilities are at low rates, while foreign sales are subsidized by export financing arrangements.

Unlike the strategists that dominate the Fortune 500 companies studied by Donaldson and Lorsch, AECL executives are dominated by an external capital market. This restricts their freedom to select strategy and predisposes them to be, in the words of Miles and Snow (1978), "reactors."

Displacement of Power to Government

These conditions suggest that the locus of power for strategy formulation cannot be within the company. Government has the initiative, and strategy will be influenced by that constituency more than by others. If, as Donaldson and Lorsch suggested, strategy formulation and implementation require continuity of service, deep full-time commitment, and a considerable measure of centralization of authority, it is hardly reasonable to expect government, as the external source of finance, to provide the leadership in strategic design. Tavel (1980) argued that a formal planning procedure is only as good as the "genius" of an individual who adds intuitive judgment that a formal planning process by itself rarely produces.

It goes without saying that government cannot provide the continuity of service needed. Responsibilities are divided among different departments, and the politicians' attention is fleeting. Deputy Ministers on the Board of Directors of AECL attend irregularly, and even then they are hurriedly briefed by junior officials.

Of the executive officers in 1984, only A. J. Mooradian, Senior Vice-President, brought to his position the continuity of service with AECL that Donaldson and Lorsch argued is the hallmark of successful corporate management. It is not an exaggeration to say that the executive officers who presently guide the business are, for the most part, new to the company since 1978.

AECL as an Organization

Everyone this writer spoke to at AECL acknowledged that the corporation has been transformed since 1978. Until then, the company culture reflected its origin as being essentially a government R&D laboratory. Commercialization has always been envisaged as subordinate to the main mandate – research into nuclear physics and reactor technology.

Whether or not a commercial orientation can successfully be grafted onto an R&D organization with a 30-year history of success, as measured by its internal values, is yet to be evaluated.

Managing Technologically Complex Systems

Much has been written about managing technologically complex, large systems. Sayles and Chandler (1971) reported on a three-year intensive analysis of both NASA and the U.S. Atomic Energy Program. What strikes one about this literature is the enormous managerial achievements needed, even in the absence of a commercial-market orientation. Failure is frequent, and success is frankly surprising. Since reading these accounts, the writer holds his breath whenever NASA launches a vehicle. (The preceding sentence is from an earlier draft written before the Challenger accident; and the author has left it in this final version for effect.) As of 1971, Sayles and Chandler reported that failure was common in U.S. military programs, but also in "perfecting high-speed trains, in the fabrication of high-pressure nuclear vessels, in the manufacture of 'heavy water' and in advanced electronic and construction projects" (p. 4).

Sayles and Chandler concluded that the management of large development systems is different from traditional commercial management:

> Traditionally, managers are taught to identify their ultimate ends and purposes, set objectives that will help attain these, and then develop operational plans. Unfortunately, this comforting and logical sequence gets upset in the real world of large systems. Clear objectives often disguise conflicting purposes reflecting the divergencies among the temporarily allied groups in the federation. Existing operational techniques often seek objectives that they can implement, rather than the other way around. Planning turns out to be a dynamic, iterative process. This inevitably disperses authority, since a small group of expert, high-level "planners" cannot define strategy (p. 4).

As a development project, CANDU seems to deserve the high marks its own participants are quick to give it. There have been numerous glitches along the way, but the system is the only one among many to have survived, albeit on a small scale, as a competitor of the U.S.-sponsored, pressurized, light-water reactor.

The Neglect of Heavy Water

The most serious fault in the program is the almost cavalier attitude that seems to have prevailed about the availability of heavy water, and the ease with which this vital product could be made available. (See Table 4-2 for a list of heavy-water facilities.) There seems little doubt that difficulties with heavy-water production and uncertainties about its price undermined CANDU's marketability at certain key moments. It certainly has had much to do with Britain rejecting the CANDU for light-water technology.

The neglect of heavy-water development is less surprising if AECL's mandate is perceived to be nuclear engineering. With hindsight and from a distance, AECL management in the 1960s can be forgiven if they faced inward and treated their mandate as a requirement to develop the CANDU system in the same way as NASA directed itself to place a man on the moon.

Table 4-2

Status of Canadian Heavy-Water Capacity

	Normal capacity	Status
	(Tonnes/year)	
Nuclear plants:		
Ontario Hydro		
Bruce HWP-A	800	– operating
Bruce HWP-B	800	– operating
Bruce HWP-C	(800)	– cancelled during planning stage
Bruce HWP-D	(800)	– 1/2 mothballed; 1/2 suspended
AECL		
Glace Bay HWP, Nova Scotia	400	– operating
Port Hawkesbury, Nova Scotia	400	– operating
La Prade, Quebec	(800)	– mothballed before completion

SOURCE Canada, Department of Energy, Mines and Resources, *Nuclear Industry Review: Problems and Prospects, 1981-2000* (1982), p. 12.

Atomic Energy of Canada Limited does not perceive its history that way. They believe their efforts were market driven rather than pushed by technology. According to an official brief, "R&D programs and schedules were determined by mission requirements" (Robertson 1984). Maybe so, but the choice of mission seems to have received precious little attention. From February 1959 until the mid-1970s, the mission seems to have been to develop CANDU in partnership with Ontario Hydro. Only during the past decade has AECL turned to the international market, and here the firm finds itself pre-empted. This marketing effort has been so half-hearted that one wonders to what extent it was undertaken by senior management seeking only to respond to pressures from government and firms manufacturing systems for the CANDU.

In short, commercial responsibilities were incidental to senior management, though necessary in order to maintain some business for manufacturers and some slight possibility of a return for taxpayers.

By 1976 it became evident that Ontario would not be ordering many more reactors. But until 1974 the demand for electricity grew at a rate of 7 per cent per annum, so that if CANDU could displace coal in Ontario alone, future prospects seemed substantial enough to maintain a reasonably large industry from Canadian sales alone.

Sims makes much of the research "syndrome," which gives the firm the confidence that its talented people can be diverted successfully to any technical problem. He may well be right, but it is just this "arrogance of talent" that is needed for a mission-oriented development project. Senior management remained true to its organizational constituency; to have done otherwise would have courted disaster on the home front in order to chase a "will o' the wisp" in the international market that might never have been realized.

Changes at AECL Since 1978

Since 1978, the President of AECL, James Donnelly, has altered corporate management policies to foster market orientation. The "Future Executive Criteria" of the company (Policy #20102, May 1984, p. 13) places market orientation in first place among a long list of qualities for managers. This is followed by general managerial qualities like leadership and interpersonal skills; a good team player; sensitivity to external issues; synthesis and strategic thinking; entrepreneurial ability; a change agent; and, lastly, routine professional and managerial competencies. Much emphasis is placed upon the manager's responsibility to bring along promising juniors. Of course, every organization will have an "informal" human resources policy that may conflict with the formal structure. Nonetheless, the writer's interviews confirm that the policy has the full support of senior management, even if resistance is found in the ranks. Within the firm, James Donnelly seems to be appreciated for his managerial acumen, but he does not seem to command the same respect as his predecessors. This, of course, probably reflects a healthy tension that accompanies an effort to realign the structure and culture of the organization.

The Executive Performance Incentive Plan for senior management reflects a similar concern for bottom-line performance. The incentive standard is 15 per cent of annual salary. This standard can be withheld or exceeded, depending upon corporate performance and the individual's performance rating. Though hardly an enormous bonus in view of the relatively low salaries earned by the senior executives, it is a significant commitment to performance orientation.

Though AECL executive compensation is not in line with that of the Fortune 500 companies, it is reported to be equivalent to the salaries earned by executives in selected Canadian engineering firms, as collected by Hay and Associates. This is just a surmise on the part of the writer, but it may be that executives in Canadian subsidiaries of major U.S. corporations are not paid to be the driving force in a strategic management scheme. They still have some way to go to reach the centre of power in their organizations, and their salaries reflect the fact that less is expected of them. The same may be true of AECL executives, AECL being a branch operation of the Canadian government. Unfortunately whatever expertise there is in strategic management within the Canadian government, it is directed elsewhere.

Nonetheless the contrast between AECL before and after 1978 is impressive. Until 1978, top salaries were linked to civil service rates and vice-presidents earned a rate equivalent to an assistant deputy minister. Considering the high degree of compression in civil service ranks, serious compression must have existed between entry level engineers and senior managers. Thus, as with universities, all incentives are to stay in the ranks and to avoid upward mobility.

The crisis in the mid-1970s led the Board to reconsider salary policy and to recruit a president from outside. The new President, James Donnelly, has experience in international projects, among other things in the pulp and paper business and for General Electric (U.K.) as a project manager in the British nuclear industry. The Executive Vice-President comes from Control Data. Apart from higher salaries for executives, AECL moved to correct its weakness at the project management level. Commercial practices were adopted with substantial bonuses for performance. Presently AECL holds a 13 per cent share in a project management firm called "Nuclear Project Managers," which supplies project management on a contract basis. Evidently, project management has been a weakness that in the past tarnished AECL's reputation in Argentina, as well as on Canadian projects. Many analysts attribute part of this problem to the divided responsibilities for managing construction and designing the different components of the power stations.

Though salaries are not tied to those in the public sector, AECL's status as a Crown corporation has caused it to be subject to the Public Sector Compensation Restriction Act (the 6-5 program), and in recent years this has interfered with the operation of the executive compensation program described above.

The most significant departure in policy is the stress placed on "business opportunity development teams" – a sort of in-house "strategic business unit" that fosters commercialization of the rich human resource skills to be found especially in the Atomic Energy Research Company.

Evidence has not been collected on the success record of these teams, nor even on the rewards available to successful in-house entrepreneurs. There is, however, a distinct impression that the senior executives envision these teams as vehicles for energetic and gifted people to use in order to enjoy rapid promotion.

Certainly the emphasis is on capitalizing on existing resources in numerous small ways rather than on waiting for numerous CANDU orders to become a reality.

One problem the company faces is that entrepreneurship is usually a young man's endeavour. Most corporate spinoffs involve employees under 30 years of age. At AECL the personnel of the Research Company is aging. The company has operated at a static level for a decade and is hiring fewer young graduates than it used to.

In conclusion, until 1978 the organization was mission- rather than business-oriented. Management was not profit-oriented, and marketing and management training were unheard of. The company seems to have been guided by a determined mission, but its strategy as a commercial operation was poorly articulated. This is not to say that the implicit strategy adopted by AECL was not right for the times. It is simply that the strategy was vaguely expressed, and many outside AECL, including the government, may have had quite a different perception of what AECL was supposed to be doing.

Since 1978 the company has taken stock of a need to restructure itself if it is to survive a period of reduced government support for R&D and few, if any, new orders for CANDU reactors. Whether it can survive this period of drought is yet to be seen, but a casual observer walks away feeling that every possible avenue for change is being explored. Nonetheless, success in restructuring the organization will be an empty victory unless senior managers make some real headway in the firm's product market.

The Product Market

Diversification

The management of AECL is not now, nor has it ever been, sufficiently independent of external forces in the industry to be able to manoeuvre skillfully in the marketplace. To begin with, it is likely impossible for AECL to consider diversifying outside the domain of those powers conferred on the Minister of Energy, Mines and Resources by subsection (1) of section 10 of the Atomic Energy Control Act, thus opportunities for diversification as a means of spreading risk are limited. From the outset, the firm did expand into commercialization of the sale of cobalt and other isotopes for medical-treatment purposes. Unfortunately, and as might have been expected, profits from this source for support of the firm's central activities have only been available fleetingly as new entrants have developed alternative technologies and successfully challenged AECL's dominant position in this market. The response by AECL to this challenge was documented in Sims (1981) and is only of peripheral interest here.

Without much hope of diversification AECL management has necessarily become captive of the market for nuclear reactors. In the 1950s, only two domestic utilities were large enough to be potential buyers of AECL reactors. One of these, Hydro-Québec, proceeded with massive hydro developments, even at a time when nuclear energy was being touted as soon able to produce meterless electricity. Thus Ontario Hydro emerged as the only major buyer. One other sale has since been made to New Brunswick. At the moment, there is thought to be some potential in Quebec and the off chance that AECL may place a reactor or two in British Columbia and another one in the Maritimes.

Integration

On the supply side, AECL is almost alone in the world as a seller of nuclear reactors while not being an integrated manufacturer. Integration by the nuclear component manufacturers, backward into design and forward into marketing, was strongly recommended by Lortie and Schweitzer (1981) in a Secor Inc. report commissioned by the private engineering and manufacturing firms in the industry. Competition from the private sector is unlikely to threaten AECL because the immediate prospects for the industry are so poor that no private money will try to go it alone. At the very worst, AECL may, through manufacturer pressure on the government, lose some further independence by being forced into a joint venture.

At home, AECL is challenged by powerful and independent buyers (Ontario Hydro has virtually integrated backward into every phase of nuclear reactor design and construction except research), and by a weak but still potentially influential supply industry. Abroad, the firm faces active competition in open markets, while some major markets are closed to foreign producers. Nor is AECL even guaranteed the Canadian market. If a provincial hydro company were to opt for a U.S. light-water reactor, the political battle lines would be drawn, and it is far from certain whether AECL and the Canadian supply industry could win such a battle. Caught in this uncomfortable position, AECL management is "stuck in the middle," in an "extremely poor strategic position" (M. Porter 1980, p. 41).

Product-Market Strategy

In order to develop a particular product-market strategy, the firm must first answer two simple questions that are at the heart of any successful business strategy:

1) What are we selling, and to whom?

2) Who are our actual and potential competitors, and how are they positioned?

Though simple enough to ask, these questions are often overlooked and taken for granted.

Until recent years, insufficient information was available to determine the nature of the nuclear reactor market and therefore no one was able to answer the above questions. Strategists have had to act on assumptions, which amounted to "stabs in the dark." The leaders, in coming to grips with uncertainty, have been two U.S. firms and a thumbnail sketch of their business strategies, compared with those of the French nuclear program, provides a good starting point for analyzing the Canadian industry. Though in many respects, according to Bupp and Derian (1978), the U.S. nuclear program is the biggest failure of all, it remains the biggest, and by virtue of this, dominates the world market in which AECL finds itself operating. Before turning to the foreign nuclear programs, we first outline the strategic options avaiiable to producers in this industry.

Strategic Roles – Cost Leadership; Differentiation; Focus

A strong strategic position is one in which the firm successfully establishes itself in one of the following roles – that is, as:

a) overall cost leader,

b) differentiated producer, or

c) focused producer.

A cost-leadership strategy may force a firm to enlarge its scope to include the world market. In those industries that enjoy significant economies of scale, return to standardization, or rapid economies from learning and experience, the industry will become a *global* one. The lowest cost producer will be the one that succeeds in operating at a scale that others cannot adopt. When a technology is new, many firms may seek the dominant position in world markets, but only a few can survive when the mature stage along the product-cycle curve is reached. Countries that assure themselves a domestic monopoly by protection may succeed if their market is sufficiently large and they compete effectively in export markets. If protection is real, in the sense that domestic producers are unable to sell abroad in competition with other suppliers, then the strategy fails and the domestic technology inevitably falls further behind.

Differentiation can be achieved along numerous dimensions, including quality perception. For products sold under brand names, differentiation is a strategy for finding a niche in the consumer's mind. For producers of industrial goods, especially those products sold infrequently and in large units, the differentiation strategy is more problematic, and buyers are likely to be as professional as sellers. When, however, information is scarce about both the product's performance and its reliability, there will be a tendency, even for professional buyers, to turn to the market to reinforce their analysis. Instead of relying on their own judgment, buyers will be prone to follow the leader and seek security through shared responsibility. This herd instinct, probably more influential on buyers in bureaucratic circumstances, favours the dominant firm in the market. Thus differentiation may not be a virtue, when a low-cost, large-scale producer is able to gain muscle in the market that smaller producers cannot displace. Nor is the buyer's instinct entirely irrational since the dominant technology will likely benefit from greater R&D effort and thus be more likely to remain ahead of its rivals.

The focus strategy involves both specialization and dedication to a particular segment of the market. When the mass producer must offer a homogeneous product, reduce service quality, and otherwise spread himself thinly, a firm may be able to exploit a profitable segment of the market despite being a higher-cost producer.

The U.S. and French Industries

Origins of the U.S. Industry

In 1951, Westinghouse began to build the first U.S. reactor for commercial power generation at Shippingport, Pennsylvania. Built together with a utility and supported by the U.S. Atomic Energy Commission, this reactor was a small demonstration unit. Orders began in earnest in 1955, but the expansion phase of the industry occurred between 1965 and 1968. All orders received until 1976 are listed in Table 4-3.

It is evident from Table 4-3 that when massive orders were placed, beginning in 1968, there was virtually no operating experience with a large nuclear station. In 1965, worldwide there were only 902 MW of installed capacity, all from stations begun prior to 1960.

The impetus for this spate of ordering was the Oyster Creek plant supplied by GE to Jersey Central and Light Company. The announcement in December 1963 of a plan to build a 515-MW light-water reactor for the first purchase to be justified as an "economic" decision, not just a developmental one. The capital cost of the plant was estimated at $100 per kW of installed capacity, and the capacity factor of the plant was forecast to be 88 per cent over the first half of the expected 30-year life of the plant. According to Jersey Central, nuclear would cost the equivalent of coal-fired power, with coal delivered at 20 cents/mbtu. At the time, Jersey was paying 29 cents/mbtu for coal.

Bupp and Derian (1978) documented how unsparingly the industry criticized the one spokesperson from the utility industry, Philip Sporn, who was skeptical about those figures. Even Sporn, however, stressed the improvements in coal- and oil-fired power generation that were still contemplated, rather than question the claims of nuclear reactor salesmen.

Until 1965, Westinghouse and General Electric sold eight reactors on a fixed-price turnkey basis (Table 4-4).

Table 4-3

Growth of Nuclear Power in the United States, 1955-76

	Initial number	Cancellation	Net amount	Number	MWe	Number installed	MWe
1955	5	–	5	–	–	–	–
1956	2	–	2	–	–	–	–
1957	2	–	2	–	–	–	–
1958	3	–	3	–	–	–	–
1959	1	–	1	–	–	–	–
1960	–	–	–	1	200	1	200
1961	1	–	1	1	175	2	375
1962	1	–	1	1	265	3	640
1963	4	–	4	1	140	5	780
1964	–	–	–	3	50	8	830
1965	7	–	7	1	72	9	902
1966	21	–	21	1	90	10	992
1967	31	–	31	1	40	9	1,004
1968	16	–	16	2	1,025	10	2,007
1969	8	–	8	2	1,260	12	3,267
1970	15	1	14	3	1,796	15	5,036
1971	21	1	20	6	3,615	21	8,678
1972	38	5	33	8	5,673	29	14,351
1973	37	5	32	7	4,513	36	18,864
1974	33	11	22	11	9,527	46	28,351
1975	4	6	–2	10	8,837	56	37,188
1976	3	10	–7	3	2,627	59	39,815

SOURCE David W. Montgomery and James P. Quirk, "Cost escalation in nuclear power," National Science Foundation (Pasadena: California Institute of Technology, 1976).

Table 4-4

Estimated Losses on Nuclear Reactor Turnkey Projects*

	Reported cost	Estimated cost	Estimated loss
		($ Millions)	
General Electric			
Oyster Creek	91	170	79
Dresden 2, 3	230	413	183
Millstone	97	182	85
Quad Cities 1, 2	250	448	198
Monticello	105	168	63
Total	773	1,381	608
Westinghouse			
San Onofre	97	131	34
Ginna	83	161	78
Robinson	78	179	101
Point Beach 1, 2	128	329	201
Connecticut Yankee	92	149	57
Total	478	949	471
Combined total	1,251	2,330	1,079

* U.S. Atomic Energy Commission Report # WASH. 1345 (October 1974), entitled *Power Plant Capital Costs* and cited in Montgomery and Quirk (1976).
SOURCE Montgomery and Quirk, "Cost escalation in nuclear power" (1976).

By 1967, U.S. utilities had placed orders for 75 reactors, totalling 45,000 MW of capacity, from four U.S. manufacturers. After the first eight orders, vendors stopped offering turnkey projects; henceforth risk was shared with the utilities. Nonetheless, competition was severe, and many selling techniques to make reactors attractive to utilities were used. For instance, Westinghouse offered to supply uranium to reactor customers at a fixed price for the life of the equipment. The consequences of this offer are well known (see Joskow 1977), because of the failure of Westinghouse to supply and subsequent court proceedings.

The actual capital costs of plants entering service in 1975 were about three times higher in real dollars than those sold on a turnkey basis (Table 4-5). Many believe that this increase was due to poor forecasting, combined with "loss leadering" on the part of GE and Westinghouse. But Montgomery and Quirk (1976) concluded that the increase was due to a combination of bottleneck problems in the nuclear industry, which expanded too quickly, and regulations that delayed construction and added costs. Until 1970 the bottleneck problems predominated, leading, after 1967, to a 30 per cent annual rate of increase in labour costs and a decrease in labour productivity. This rate

Table 4-5

Capital Costs of Nuclear Units Coming on Line in the United States, 1968-74

		FPC*			AEC†		
			Capital cost			Capital cost	
		MWe	Total	per kilowatt	MWe	Total	per kilowatt
Average by year:			($ Millions)	(Dollars)		($ Millions)	(Dollars)
1968							
T	Connecticut Yankee	600	91.8	153	575	95.0	165
T	San Onofre	450	80.9	180	430	98.0	228
	Average	525		164	503		192
1969							
NT	Nine-Mile Point	620	162.2	262	610	151.0	247
T	Oyster Creek	550	89.9	163	530	83.0	157
	Average	585		215	570		205
1970							
T	Dresden 2	810	92.3	114	809	94.0	116
T	Ginna	517	83.2	161	420	65.0	155
T	Millstone	662	96.8	146	652‡	92.0‡	141‡
T	Point Beach 1	524	74.0	141	497	61.0	123
	Average	628		138	575‡		127
1971							
T	Dresden 3	810	103.8	128	809	100.0	124
T	Robinson 2	769	77.8	101	700	76.0	109
T	Monticello	569	105.0	185	545	89.0	163
NT	Palisades	812	146.7	181	700	118.0	169
	Average	740		146	681‡		139‡
1972							
T	Point Beach 2	524	71.4	136	497	54.0	122
NT	Vermont Yankee	514	172.0	335	514	154.0	300
NT	Pilgrim	655	231.5	353	644	120.0	186
NT	Surry 1	847	146.7	173	788	251.0	319
NT	Turkey Point 3	760	108.7	143	693	119.9	159
T	Quad Cities 1, 2	1,657	200.1	121	1,600	250.0	156
	Average	708		188	693		217
1973							
NT	Surry 2	848	250.2	295	788	149.0	189
NT	Turkey Point 4	760	122.5	161	693	106.0	153
NT	Zion 1	1,089	276.0	251	1,050	262.0	249
NT	Maine Yankee	830	219.2	264	790‡	263.0‡	333‡
NT	Prairie Island 1	593	233.2	393	530	200.0	377
NT	Fort Calhoun	481	173.9	361	457	175.0	383
NT	Oconee 1	887	155.6	176	886	163.0	184
T/NT	Indian Point 2	1,013	206.1	203	873	212.0	242
	Average	814		251	753		240
1974							
NT	Arkansas Nuclear 1	902	233.0	258	850	239.0	281
NT	Arnold	566	202.2	357	535‡	277.0‡	518‡
NT	Zion 2	1,098	289.9	264	1,050‡	271.0‡	258‡
NT	Prairie Island 2	593	172.2	290	530	200.0	377
NT	Cooper	835	246.3	295	778	296.0	380
NT	Peach Bottom 2	1,152	628.5	546	1,065	537.0	504
NT	Three-Mile Island	871	398.3	457	819	406.0	496
NT	Oconee 2	887	320.8	361	817	160.0	184

Table 4-5 (concl'd.)

		FPC*			AEC†		
			Capital cost			Capital cost	
		MWe	Total	per kilowatt	MWe	Total	per kilowatt
			($ Millions)	(Dollars)		($ Millions)	(Dollars)
NT	Kewaunee	535	202.2	378	541	201.0	372
NT	Peach Bottom 3	..§	..§		1,065	226.0	212
NT	Oconee 3	..§	..§		871	166.0	191
	Average	827		362	821		329

* FPC = Federal Power Commission.
† AEC = Atomic Energy Commission.
‡ Millstone is classified as a 1971 unit by AEC and appears in 1971 averages; Zion 2 and Arnold are classified as 1975 units; and Maine Yankee is classified as a 1972 unit, and appears in 1972 averages.
§ Not shown in 1974 FPC.
NOTE T = turnkey; NT = non-turnkey.
SOURCE Montgomery and Quirk, "Cost escalation in nuclear power" (1976).

outpaced the rate of inflation, which was modest during the late 1960s.

The heavy purchasing of nuclear reactors by utilities was a rational decision. Electricity demand was then growing at a rate of 7 per cent per year. By ordering nuclear stations, utilities were simply diversifying their expanding sources of generating capacity. As regulated firms, they were predisposed to favour high capital costs by a regulatory system that was bound to award rate increases in relation to the growth of a rate base. Coal and oil generation capacity continued to grow, but utilities took the precaution to backstop themselves should the promise of nuclear power be realized. At the same time, new mining and environment legislation threatened higher coal costs, which in fact drove coal prices up in 1969, well before OPEC's pricing moves. Furthermore, the U.S. protected its oil industry so that oil was at least twice as expensive inside the United States as outside.

The Decline of Demand for Nuclear Reactors

Thus, with still no operating experience to rely upon, U.S. utilities continued to place orders in large numbers until 1974. The OPEC crisis in 1973 seemed to add impetus to the industry, but the extra demand soon disappeared. This is because by 1974 the 46 stations ordered prior to 1966 were operating, and 28,351 MW of installed capacity were in place. Operating experience failed to live up to prior expectations. The capital costs for nuclear power were about three times those forecast or at least twice those forecast after taking inflation into account. Furthermore, the actual operating rates of nuclear plants did not achieve the forecast rate of 88 per cent, uranium prices skyrocketed, and maintenance was more expensive than that for a similar-sized coal station. All these factors together have caused electricity from the present generation of U.S. nuclear plants to cost between 10 and 12 cents per kilowatt hour in 1982 dollars. (Flavin 1974*b*, p. 192). This is reported to be 65 per cent above the cost of coal-fired plants, though the basis for this conclusion is not reported. Also, the demand for nuclear reactors virtually disappeared when it became quite clear that electricity demand would not be growing at the same rate as prior to 1973. As a result, since 1975, cancellations have outnumbered orders for nuclear reactors. The present sad plight of utilities trying to complete stations that were ordered prior to 1975, while faced with high real interest rates is too well-known to bother reviewing here.

The Influence of the U.S. Program Abroad

Outside the United States, oil prices continued to drop in both nominal and real terms until 1970. In Europe there was greater concern for safeguarding markets for coal than for allowing nuclear power to displace it. Nuclear developments therefore remained largely experimental and government-supported with an eye, first, to scientific pursuits and, second, to national prestige, and only inadvertently at then current economics.

By 1970, the love affair between U.S. utilities and nuclear reactors, though essentially based upon expectations, was having some impact abroad. To exploit this interest, Westinghouse and GE founded subsidiaries abroad and also licensed foreign producers. The major impact on world markets, however, is due to French initiatives. Britain went its own way, based on great foresight about the weaknesses of the U.S. program. Despite this, it could not avoid failure in its own program. Germany developed its own light-water reactors, which are proving to be among the most reliable in the world.

Experience in all three countries is relevant to evaluating Canada's program. Burns (1980) has contrasted failure in the U.K. program with success in the U.S. program and attributed this to the different roles of public and private enterprise. But Bupp and Derian (1978) concluded that this was not the case; they believe that the U.S. program turned out to be the biggest failure of all. In contrast, the French, it is claimed, have organized things logically and are succeeding. This conclusion flows from the projection of those in the nuclear industry who are confident that central authority, combined with technological optimism, can conquer the world. The fact is that it is too early to say whether the French program will be successful or not, even though oil prices have unexpectedly skyrocketed since the French first committed themselves to the nuclear option.

French Success or Failure

Because the drop in electricity consumption is worldwide, France is also having trouble with its program. By committing itself to a single reactor design and prescheduling domestic orders, France hoped to reduce costs. The industry geared up to produce six reactors per year. Today however, no new reactors are needed. To support the program one unit was ordered in 1984 and another in 1985. Neither is needed. Furthermore, reactor performance is not up to expectations. The French strategy has built in rigidity which may well outweigh any of its benefits. Already Électricité de France (EDF) is closing down modern coal-fired stations and subsidizing electricity consumption. In France, the pressurized light-water reactor was selected as the single technology to be developed over all other types, but not following a rational analytic evaluation. The outcome emerged from a highly irrational interagency conflict. In the end, EDF won the day because of the willingness of its chairman and influential president to resign in order to back up EDF's position. Thus EDF succeeded in displacing CEA – a government agency similar to AECL. Had Ontario Hydro decided to go with a light-water option, the same sort of conflict could have transpired here. By 1974, after OPEC, the program was expanded, and Westinghouse's licensee (Creusot-Loire subsidiary, Framatome) was selected as the exclusive producer for the French market (see Vernon [ed.], 1974, p. 104).

The French decision gave an enormous boost to pressurized light-water reactors. By 1977 General Electric was reported to be curtailing its sales efforts for boiling-light-water reactors. Framatome, the French producer, looked as if it would be able to lower the costs of production by standardizing units and selling those standard units abroad as the "low-cost" producer.

The French have succeeded in articulating a firm business strategy, and they seem to have the will to proceed with it regardless of what other rivals may choose to do. They have thereby achieved a unity of purpose that has escaped other nations' industries. Their scientific effort is devoted to the breeder-reactor program, which they believe will largely replace the light-water reactor in some 20 or 30 years' time. In the meantime, their engineering skill is being applied to reduce the cost of producing a generation of light-water reactors at the rate of about six units per year. It is reported that the French light-water reactors cost about $1,000/kW excluding the interest cost during the construction period. This is thought to be about 30 per cent below the capital cost of a CANDU reactor.

The Canadian Product-Market Strategy for the CANDU

Nuclear power moved quickly through development and demonstration to the dissemination stage. Table 4-6 (DeLeon 1980, p. 299) shows how important timing can be. The United States was seven years ahead of the rest of the world in the demonstration stage and about four years ahead in the commercialization and dissemination stage of the technology. But nuclear reactors take between six and ten years to build, and there are further delays in acquiring operating experience with the reactor. Thus the U.S. time advantage is small relative to the time period for reactor construction.

Though Canada moved its program rapidly, some think too rapidly, it still missed the major period of ordering in the United States, which lasted from 1966 to 1974. As luck would have it, Pickering was not in place soon enough for CANDU to take advantage of the orders in 1973 and 1974 that were stimulated by the OPEC crisis. Once Pickering's excellent operating experience became better known, the growth of the demand for electricity had clearly declined and with it went much of the market for nuclear reactors.

Little Emphasis on Export Marketing

In the writer's judgement, until 1975, AECL had not considered foreign markets important to the development

Table 4-6

International Comparison of the Timing of Nuclear Technology (Development, Demonstration, and Dissemination)

		Development stage	Demonstration stage	Dissemination stage
United States				
PWR	1947	Shippingport (1951)	Yankee-Rowe (1961)	Yankee-Haddam (1968)
BWR	1947	Vallecitos (1967)	Dresden (1960)	Oyster Creek (1969)
West Germany				
PWR	1955		Obrigheim (1969)	Stade (1972)
BWR	1955	Kahl (1962)	Grundremmingen (1966)	Wurgassen (1972)
Soviet Union				
LWGR	1949	Obinsk (1954)	Beloyarsk 1-2 (1954-67)	Beloyarsk 3-4 (1971-72)
PWR	1949	"Lenin" (1956)	Novovoronezh 1-2 (1954-69)	Novovoronezh 3-4 (1971-72)
BWR	1949	Melekess (1962)		
Canada				
HWR	1945	NPD (1962)	Douglas Point (1967)	Pickering 1-4 (1971-73)
France				
GGR	1949	Marcoule G2, G3 (1959-60)	Chinan 2-3 (1965-67)	St. Laurent 1-2 (1969-71)
PWR			Chooz (1967)	Fessenheim 1-2 (1976)
England				
GGR	1946	Calder Hall (1956)	Magnox Reactor (1962-71)	1965
AGR		Windscale (1963)	Dungeness B (1976) 1974	
SGHWR		Winfreth (1967)	1978	

NOTE PWR – Pressurized-Water Reactor.
BWR – Boiling-Water Reactor.
LWGR – Light-Water Graphite Reactor.
HWR – Heavy-Water Reactor.
SGHWR – Steam-Generating HWR.
GGR – Gas Graphite Reactor.
AGR – Advanced Gas Reactor.

SOURCE P. DeLeon, *Development and Diffusion of the Nuclear Power Reactor: A Comparative Analysis* (Cambridge, Mass.: Ballinger Publishing, 1980), p. 299.

of the CANDU. During the 1960s and 1970s, the forecasts of Ontario's electricity demand alone seemed to indicate a bright future for the CANDU should its development be successful (Chart 4-1).

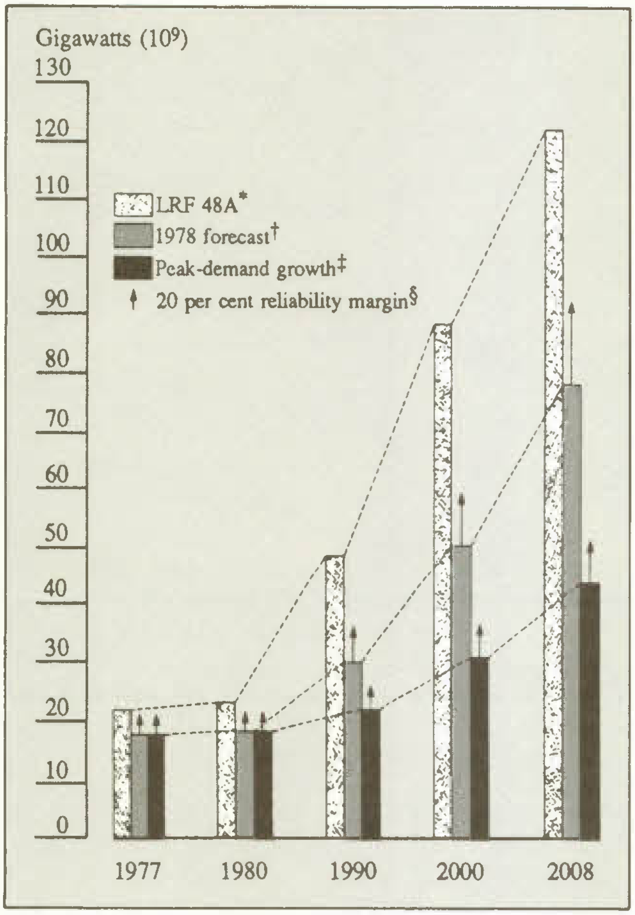
As late as October 1975, Ontario Hydro announced plans to spend $19 billion, mostly on expanding nuclear facilities over 10 years. As part of its long-range forecast (LRF 48A), it projected 29,000 MW between 1990 and 2000, and 39,000 MW more to 2008. Thus Ontario alone would be providing about 80,000 MW of additional electricity over 30 years. This averages out to about 2.7 GW per year, or the equivalent of four and a half 600-MW stations each year.

This level of ordering is just about what the present capacity of the Canadian nuclear industry can handle (see Table 4-7). If the then expected Quebec demand were added to these Ontario forecasts, the domestic industry would have needed to be expanded considerably more. Thus, without a single export order, the Canadian nuclear industry seemed to be well positioned for a long period of self-sustaining if modest growth. By the time the expansion phase to 2008 would have been completed, old reactors would need to be dismantled and replaced. Optimists for the CANDU saw it outlasting the light-water reactors (LWR) because the CANDU can, like the breeder reactor, be adapted to use plutonium recovered from other reactors and thorium instead of uranium. If the breeder reactor technology were to falter or should the price of uranium remain modest, an improved CANDU could have a bright future for a very long time.

The above forecasts of Canadian demand for nuclear reactors date from 1975. In 1974, AECL was forecasting Canadian demand of 130 GW by the year 2000 (Lortie and Schweitzer 1981, p. 38). On that scale, nine 600-MW reactors a year would be in production for the Canadian

Chart 4-1

Ontario East System Capacity and Peak-Demand Scenarios



* Ontario Hydro, Long-Range Forecast 48A, 1975, for installed electrical capacity.
† Ontario Hydro, forecast of peak demand, 1978.
‡ Ontario Hydro, 1980 demand forecast is for growth at 3.4 per cent per year.
§ For illustrative purposes we have added 20 per cent to peak-demand figures to yield an installed-capacity figure. Cf. 1977 figures.

SOURCE Adapted from Royal Commission on Electric Power Planning, Interim Report, *A Race against Time* (Toronto, 1978), p. 32; see also C. A. Hooker et al., *Energy and the Quality of Life: Understanding Energy Policy* (Toronto: University of Toronto Press, 1981), p. 55.

market alone. The difference between the 1974 and 1975 forecasts is the result of a drop in the growth rate of demand for electricity from over 7 per cent per annum to just about 5 per cent. The actual decline was much sharper, but there then remained some uncertainty as to how long the growth rate would remain below the trend established over the previous two decades. By 1979, AECL was forecasting Canadian demand to the year 2000 of between 25 and 65 GW. It is today clear that Ontario will not likely add any additional capacity beyond the Bruce and Darlington plants unless coal prices explode upwards, so the low end of the 1979 forecast is fairly certain not to be exceeded in Canada unless demand for electricity in Quebec increases and the cost of remaining opportunities for hydro developments becomes unattractive.

In 1974, AECL expected worldwide demand to the year 2000 to be 40,000 GW; it was revised downwards in 1977 to 1,543 GW. As of 1974, if CANDU were to capture just 5 per cent of the world market, AECL could have expected to sell more than 130 of the 600-MW units per year for 25 years. In 1977, to capture 5 per cent of the market would have meant that worldwide sales would amount to only five per year. (For market-share data, see Table 4-8.)

At this time, five sales per year would appear to be the salvation of the CANDU project, but the 1979 projection turns out to have been wildly optimistic. By 1982, a review of the nuclear industry by Energy, Mines and Resources (EMR) made it clear that there was a real possibility that there would be no new domestic or foreign orders for the CANDU for the next decade. Today, however, there is a possible sale of one reactor to Turkey, and it is in an advanced stage of negotiation.

In 1980, Canada had the capacity to produce nuclear reactors with a total rated capacity of 3 GW per year, just about 5 per cent of world capacity and in line with Canada's share of the world market. In contrast, U.S. firms have about 25 GW of capacity in place, and their sales prospects are as poor as those for the CANDU (Lortie and Schweitzer 1981, p. 140).

It is difficult to imagine today that in the early 1970s the risk associated with CANDU developments was focused on success in technical development rather than in marketing. With the Tennessee Valley Authority claiming that nuclear power was cheaper than coal-generated power, even in the coal fields, how much truer would this appear to be in Ontario where coal is virtually all imported from the United States? Nor was the TVA making a casual assessment; it backed up its analysis by ordering two giant light-water reactors. From AECL's vantage point the worldwide market had been created by U.S. marketing efforts, and a small niche for the CANDU was more than sufficient to rationalize the Canadian R&D effort. The partnership with Ontario Hydro assured for CANDU its most important market; all other sales were gravy.

Certainly the above strategic considerations explain why AECL ceded the world market to CGE until 1968. In the late 1960s the "only game in town" was building Pickering and hopefully demonstrating its capabilities.

Table 4-7

Estimated Worldwide Utilisation of Nuclear Reactors Production Capacity in the 1980s

	Manufacturing capacity of installed reactors	Estimated wattage likely to be ordered in the 1980s	Domestic workload that is likely to exist*
	(GW per year)		(Per cent)
Canada	3	0.5–1.0	16–33
France	7	3–4	43–57
West Germany	6–8	1–2	12–33
Japan	6	3–4	50–57
Sweden	1–2	0–0.5	0–50
Britain	1–2	0.5–1.5	50–100
United States	25–30	2–7	7–28
Export markets	–	4–6	8–20†
Total	49–58	14–25	24–51

* Share of total capacity being utilized by domestic nuclear reactor construction.
† Percentage of capacity left after domestic orders are met.
SOURCE P. Lortie and R. Schweitzer, *A Strategy for the Development and Strengthening of the Canadian Nuclear Industry* (Montreal: Secor Inc., March 1981).

Ordered in 1964, just shortly after GE's Oyster Creek announcement, the two 500-MW stations were being built at Pickering at a time when information about the costs of production and operating experience for light-water reactors was as scarce as that pertaining to heavy water (DeLeon 1980, p. 171).

No one would have imagined that the wild spree of purchases by U.S. utilities between 1966 and 1974 was to be the final phase of the market. These orders were placed without any more knowledge of operating and capital costs about the LWR than was available for the CANDU. It appeared that as long as CANDU's costs could be compared to those of the LWR, the market opportunity would remain enormous.

Strategically, then, throughout the 1960s, AECL focused its resources and energy on completing Pickering and establishing the CANDU systems. There was no need to look too far ahead in order to establish a strong presence in the international market; that market was minor and would not develop until the 1970s, when oil prices would have stopped falling and both coal and oil prices were expected to rise.

Failure to Sell in the Booming U.S. Market

Why, then, did CANDU not benefit from the ordering binge in the United States during the 1967-74 period? The writer did not come across a single contemporary account suggesting that AECL should seek a U.S. utility customer. Atomic Energy of Canada Limited decided to place all of its eggs in the domestic basket and to look for an occasional sale in Third World countries. Between 1968 and 1972, bids reported to have cost just $1 million each were offered by AECL in Romania, Mexico, Australia and Greece (Canada, EMR 1981*b*, p. 265). Excuses for Canada's marketing failure are legion, but it seems clear that during the 1960s Canada's position was undermined not by any lack of expertise in marketing, upon which so much attention has since been showered, but by two more basic factors: the uncertainty over the cost of producing heavy water; and the delay in making the demonstration reactor at Douglas Point operational.

Heavy Water in Canada's Marketing Failures

During the 1960s heavy water was selling commercially for about $30/lb. Since CANDU requires about one long

Table 4-8

Share of the Nuclear Reactor Market, by Vendor, 1980

	Domestic	Foreign*	Total	Foreign as a proportion of total reactors
				(Per cent)
		Number of reactors in operation		
Westinghouse	26	13	39	33
Framatome	12	1	13	8
General Electric	25	14	39	36
KWU	7	3	10	30
Combustion Eng.	7	–	7	–
Babcock & Wilcox	9	–	9	–
Canada	10	2	12	17
		Number of reactors under construction or on order		
Westinghouse	33	33	66	50
Framatome	39	8	47	17
General Electric	26	17	43	39
KWU	12	7	19	36
Combustion Eng.	8	–	8	–
Babcock & Wilcox	7	–	7	–
Canada	13	3	16	19

* Including joint ventures.
SOURCE Lortie and Schweitzer, *A Strategy for the Development and Strengthening of the Canadian Nuclear Industry* (1981).

tonne per MW of electricity, at $30/lb. the initial charge for a 600-MW CANDU would work out to $40.3 million or about $67/kW. Since the U.S. light-water reactor manufacturers were at the time promising capital costs in the range of $125 to $130 per kilowatt, the initial charge for heavy water alone would have been half the cost of a light-water reactor. *Nuclear Engineering International* devoted a full issue to heavy water (see "Heavy water: Special issue" June 1966, pp. 11 and 121). Evidently, problems encountered in producing heavy water would not have escaped the industry's notice. That those circumstances were not quickly overcome was made clear by DeLeon (1980, p. 169); who reported heavy-water prices as high as $50 in 1975.

Canada was forecasting that increased scale would drive the price of heavy water down to $14/lb. by the mid-1970s. At $14/lb., the initial heavy-water charge would be reduced to $30.80/kW, or about 20 per cent of the then forecast price of a light-water reactor. Considering the overwhelming importance of heavy water in the Canadian nuclear development program, the almost cavalier attitude towards the difficulty in producing heavy water reflects poorly on the whole program and on AECL in particular. Apparently, technology for heavy-water production did not seem as glamorous a field to develop as the reactor field. It was left to outsiders, affected by regional and nationalistic emotions. Atomic Energy of Canada seems to have dismissed normal caution about the difficulties of upscaling a design from a small plant to a large one.

The expense to a CANDU buyer for heavy water was critical to CANDU's success, not only because it raised the initial capital cost but also because many in the industry doubted that the CANDU system could be made sufficiently leakproof. If a considerable amount of heavy water were to leak into the containment building, then additional heavy water would be needed during operations. Atomic Energy solved the leakage problem, and now very little heavy water is needed beyond the initial fill. But during the 1960s and early 1970s there was every reason to be skeptical on that account.

Delays in Completing a Demonstration Plant of Commercial Scale

The second factor that hindered CANDU sales during the boom years for reactor sales was the delay in bringing the Douglas Point reactor into operation. Here, the weaknesses in allowing a research organization to dominate a commercial enterprise seems to have come into play. For instance, one of the sources of delay was the failure of a fuelling machine that had been redesigned by AECL during construction of the Douglas Point reactor, which was Canada's demonstration stage reactor completed three years behind schedule in 1967. The fuelling machine is a critical piece of equipment that enables CANDU to be refuelled without any downtime for the reactor. Rods are removed from and inserted into the reactor while it remains in operation. A senior, now-retired CGE official explained to the writer how CGE had successfully developed a fuelling machine for the NPD reactor. AECL decided to change the design, which later turned out not to work as expected. It took two years of work, with help from CGE, to make the new machine operational. Doubtlessly, this was not the sole reason for the Douglas Point reactor being almost three years late coming on stream. Nonetheless, the weakness of project management, combined with a desire to experiment, certainly delayed the project. Indeed, the decision to exclude CGE from the design and construction of the Douglas Point reactor is open to question on various grounds. Had the Douglas Point reactor operated successfully in 1964 and had heavy water become available at reasonable cost, it is likely that CANDU could have become a major player in world markets. In those circumstances, all efforts should have been made to get that reactor on stream in timely fashion instead of taking major risks in redesigning it during the construction phase of the project.

Ontario Hydro's Influence

The shutting-out of CGE from the design and construction of larger reactors in Ontario is frequently blamed on Ontario Hydro. Hydro took on responsibility for the conventional side of the generating station and preferred to deal with AECL as the designer. It is argued that Hydro wished to avoid becoming dependent upon a single supplier of nuclear stations, or even of components for the reactor. But whatever Hydro's intentions were, AECL seems to have proceeded without any consideration having been given to the strategic consequences of the move. The outcome is that AECL is one of the few vendors of nuclear reactors in the world that is also not integrated into manufacturing the basic components of its system. To some – Secor Inc., for instance – this is a paramount weakness in the Canadian marketing program.

Atomic Energy of Canada Limited can be excused for having acquiesced to Ontario Hydro's preferences; the latter held all the cards, being the only utility willing to co-finance reactor development. In 1964, when Pickering was ordered, Ontario Hydro and the Ontario provincial government contributed 40 and 27 per cent of the cost, respectively. Under those circumstances, vaguely hoped-for future market opportunities could hardly be expected to be able to compete with the initial financial support from Ontario.

The year 1964 was the heyday for fixed-price turnkey projects in the United States. Ontario Hydro might have opted for a U.S. light-water reactor on a turnkey basis; and CGE was willing to bid, on a fixed-price basis, for the Pickering contract but was advised that its bid would not be welcome. Instead, Ontario Hydro – in partnership with AECL and the provincial government – agreed to accept the risks of developing CANDU.

The CANDU suited Ontario because the manufacturing of components would largely be done within the province. The key component of the rival light-water reactor (the LWR) is the stainless steel calandria, which would have had to be imported into Canada. Thus, for Ontario, CANDU offered the prospects of increased domestic manufacturing, together with the efficient expansion of generating capacity. Though a deal could have been struck for domestic production of some of the components for the LWR, the biggest items and the engineering work would have had to have been imported.

Summary

We have seen that during the crucial expansionary period for the U.S. reactor industry – that is, between 1966 and 1974 – AECL was tied to a domestic market strategy. This is partly explained by its financial dependence upon the federal government and, its organizational preference for research and development but principally by its product market.

In the product market, AECL presumed that industrialized countries would exclude Canada from their markets. This was certainly a reasonable assumption, consistent with prior experience with protection in the conventional electricity-generating industry (see Burn and Epstein 1972). At the same time the United States, United Kingdom, France, and Germany were each spending far more than Canada on R&D and would be unlikely to open their borders to an imported technology. Third World countries were not major consumers of energy; they used proportionally less electricity, and their electrical networks could not support an extremely large nuclear station. In any event, competition for sales at marginal costs by industrial countries might make sales to Third World countries break-even propositions at best. It has turned out that all such sales by Canada have indeed been made at subsidized export financing rates, and the social return from such sales to the exporting nation is probably negative.

However reasonable these assumptions about market opportunities may have seemed, AECL can be faulted for not having tested those limits. Possibly along with CGE, they could have made an effort to sell reactors in the U.S. market during the 1965-74 boom.[1] Given the rush into nuclear power in the United States, regulatory roadblocks would likely have been surmountable during the early years of the period, certainly before 1970. In order to win a sale, however, CANDU would have had to offer a U.S. utility a turnkey project at a price that was no worse than that offered by U.S. reactor companies. Since the U.S. reactor manufacturers stopped offering turnkey projects in 1967, a door was left open through which a bold move might have been enormously rewarding. The sale of a Pickering-type CANDU unit in the United States to a U.S. utility would have made a real impression abroad during that critical period when operating experience was unavailable for any of the competing types of reactors. A turnkey sale in the United States would also have demonstrated AECL's confidence in its ability to acquire or produce heavy water, thereby overcoming a major hurdle in any effort to win over foreign opinion in favour of CANDU.

Instead, AECL has paid the price of being dependent upon a single market that unexpectedly evaporated. We have seen that the domestic market seemed, until 1975, to be more than adequate to support CANDU's research and development costs. But by having stayed out of the U.S. market and having failed to change the perception of CANDU at that critical time, AECL has lost its options. Since then, German, French and U.S. producers of light-water reactors have become so firmly entrenched in international markets that the odds are now against any revival of CANDU.

The Nuclear Reactor Business: Is it Necessarily a Global Industry?

Michael Porter (1980) defined a "global industry" as one in which the domestic-market position of the firm significantly improves its selling position in foreign markets. A more rigorous definition would require that a global industry be one in which no single national producer could compete at home with those rivals selling globally. By that definition, the nuclear industry was not a global industry before 1975; nor was it clear that it would ever become one.

The Experience Curve

Hopes were high for experience-curve benefits and scale economies, but the growth of the world market was expected to outpace any economic advantage that a dominant producer might gain. Whether reduced costs flow from learning is debatable; real costs have risen over time for a variety of reasons. Joskow and Rozanski (1979) found that the experience curve is real but that the shift from smaller (500- to 600-MW) to larger (1200-MW) units was accompanied by a disproportionate increase in unit prices; see, also, Zimmerman (1982). According to Joskow and Rozanski, continuous experience with a 600-MW reactor brings down costs, as does experience in building a 1200-MW reactor, but the experience gained on a 600-MW reactor does not transfer well when the jump is undertaken. Upscaling reactor size has caused more difficulties than previously anticipated; and experience has not all helped to reduce costs. Unforeseen safety problems have led to modifications, which in turn have caused capital costs to surge upwards. Komonoff (1977), in a study that has shattered the industry's confidence, found that *real* construction costs in the United States between 1971 and 1978 rose by 13.5 per cent annually. In 1982 dollars, new nuclear plants in the United States will cost an average of $2,000 per kilowatt. In Germany, capital costs rose six-fold between 1969 and 1982. That is about twice the rate of inflation. Ontario Hydro's construction costs were reported by DeLeon to be $1,700/kW, up from $400/kW in 1972, a *real* rate of increase of 6 per cent per year (other figures for 1981 vary between $1,070 and $1,350 per kW). Though that is half the rate of increase reported by Komonoff for the United States, the performance is still poor. Whatever learning and experience curve advantages Joskow was able to isolate were swamped by the rapid rise in costs, which has far outpaced the rise in the cost of building a coal-fired generating station. Given the large share of reactor expenditures committed to local construction, which is sensitive to local conditions, the nuclear reactor business is not a global business by virtue of potential economies of scale. Trying to be a low-cost producer is worthwhile, but it is not likely to be achieved simply by expansion.

Reputation and Credibility

The nuclear reactor industry may still be a global industry, despite the absence of significant economies of scale in production, rapid learning effects that push down costs, or advantages in acquiring inputs. That is because reputation and credibility are global in nature for industries that are in an emerging phase. At an early stage of the product cycle, buyers are first-time buyers, and the first sale could lead to a significant amount of repeat business. The initial sale is therefore the tough one. All rivals will have a similar inducement to discount in order to capture a new customer and thereby attract future repeat orders. Another factor that weighs in favour of describing the nuclear reactor industry as global, is that the perceived likelihood of obsolescence is particularly crucial in the market for capital goods. A global strategy may help dispel the potential customers fear over the risk of obsolescence. A producer in a small market may be unable to overcome the psychological advantage that accrues to the larger producer.

Global success encourages the belief of the potential buyer that his choice of technology will give him access to enjoyment of future improvements that inevitably seem to accrue to new technologies. On the other hand, once committed to a technology – even one that turns out to have poor prospects – it may become expensive to shift models. Training costs will have been incurred and an infrastructure will have already been put in place. For instance, buyers of light-water reactors may have built enrichment facilities, whereas users of heavy-water reactors may have invested in heavy-water production. Apart from that, different reactor types may induce applied research on local problems related to material handling and waste disposal that do not transfer readily between technologies.

Therefore, it appears that the nuclear reactor business is, by its nature, partially a global business but not exclusively so. Being a small producer need not necessarily lead to an enormous cost disadvantage in this still largely custom-made business; it is, however, increasingly likely to foreclose opportunities for export sales. This optimistic conclusion for CANDU's prospects is, however, based upon past experience and a growing market; there is nevertheless the real danger that greater R&D expenditures by others will make CANDU obsolete.

Differentiation of the CANDU

The CANDU is distinguished from its rivals by the following featured factors:

- on-line fuelling and thus, theoretically, high plant availability;

- no need for enrichment;

- heavy-water moderation and cooling;

- no need for a pressure vessel and thus relative ease in manufacturing; and

- the natural safety advantage provided by the large dump of heavy water.

The CANDU suited Canada because after the war the United States monopolized facilities for the enrichment of uranium. A heavy-water design was a means of competing without access to enrichment. Reinforcing this was the possibility of avoiding the building of a large pressure vessel, with which Canadian industry was then, and still is, unprepared to cope. The initial design of the NPD reactor called for a pressure vessel, which was ordered from the United Kingdom and remains unutilized because it was made obsolete by a design change that favoured using tubes for CANDU reactors.

But all of those features, which were thought until recently to be in CANDU's favour have lost their advantage. The United States no longer monopolizes enrichment facilities. New technologies are being developed for enrichment, which might have been expected to follow from the successful commercialization of light-water reactors. Heavy-water research continues but outside Canada, the interest in heavy-water development is mute. Global success of CANDU commercialization might have brought substantial indirect benefits through research and development aimed at reducing the cost of producing heavy water. This opportunity has been lost. Today the price of heavy water varies between $95 and $150 per lb. considerably above the $14 target set in the 1960s, even after adjusting for inflation.

Smaller countries may remain interested in buying reactors that do not depend upon having access to enrichment facilities. This is a politically motivated consideration that may not be persuasive when large-scale investments are at stake. Nonetheless, CANDU has a selling point in countries with uranium resources. Because Canada can avoid enrichment and the complex manufacturing of a calandria, even the least industrial countries could come close to becoming self-sufficient in the production and operation of nuclear reactors. For example, India proceeded to build two 200-MW CANDU-style reactors after Canada withdrew support of their nuclear reactor program. On the other hand, this advantage is offset by dependence upon the original supplier for heavy water. Few small countries without a massive CANDU program would consider investing in its own heavy-water production facility. Once a commercial-scale plant (800 tonnes/year) is built, an additional 850-MW reactor must be added to the system each year in order to keep the heavy-water plant working near full capacity. CANDU claims lower life-cycle generating costs than light-water reactors. These claims depend upon it using lower-cost unenriched uranium and upon its higher average capacity because of its design. Of these advantages, only the first was a selling point since until recently operating data were not available for many reactors. This selling point lacks some conviction because the best light-water reactors, especially

German-built ones, seem also to be rarely out of service. Much of the credit for the good in-service performance of the CANDU is attributed to Ontario Hydro's excellent reputation in the management of reactor operations.

On balance, then, the CANDU does differ from the light-water reactor, and this is thought to preserve some hope for it despite the dominance of the light-water reactor. The CANDU's assets have declined in importance, however, since enrichment facilities have become competitively available, whereas heavy-water supply remains virtually a Canadian monopoly. This remains a real liability to selling the CANDU abroad. The differentiation strategy no longer seems to be a sufficient basis for being optimistic on behalf of the CANDU, even if the world market for nuclear-generated power should recover.

Focus on Ontario

Costs of Expanding Into the U.S. Market

Atomic Energy of Canada Limited was focusing on the domestic market during the critical period for commercializing nuclear reactors. This strategy probably saved at most $100 million or so – the amount in 1965 dollars that would have been needed at that time to crack the U.S. market. That is the investment that would have been required to overcome the regulatory barrier, since initial sales in the United States could only have been made on a concessionary basis. AECL was the venturer with much to gain had CANDU become accepted in the U.S. and global markets; therefore, AECL alone should have been willing to accept the risk associated with CANDU commercialization in the United States. Meanwhile, at home, the Ontario government was willing to shoulder over half the risk. In order to sell a CANDU into the U.S. market in the mid-1960s, AECL would have had to meet GE and Westinghouse's turnkey prices, and to guarantee heavy-water supplies either free of charge or at a firm price. It might also have been necessary to assure customers of uranium supplies at firm prices.

To determine the sort of investment that would have been required, we might look to GE and Westinghouse's investment in market dominance. These two firms are reported to have lost a combined total of $1,079 million on 13 reactors built under turnkey contracts. Since the two Pickering stations cost about $220 million (Cdn.), or about $240/kW (US), Canadian reactors would have been considerably more expensive than the prices being charged by GE and Westinghouse on turnkey projects. For example, the Monticello station is roughly the same size as a single Pickering unit. It entered operation the same year as Pickering – that is, in 1971. The utility paid $105 million, but GE is reported to have lost $63 million on the sale (see Table 4-3). To the utility, the capital cost was about $190/kW whereas GE's costs were closer to $305/kW. If Pickering costs could have been translated into the U.S. market, AECL would have been able to enter with only modest cost overruns; but at the outset it would have had to accept a great deal of risk. Two significant sales in the United States of 500-MW reactors, together with assured supplies of heavy water, would seem to have placed AECL at risk for little more than a total of $250 million, even if the reactors failed to operate. This is not an unsubstantial sum, but Westinghouse and GE risked about ten times that amount (see Table 4-3). It is more likely that AECL would have risked losing, at most, $100/kW, or $100 million.

Granted this is not a trivial sum; but it is not incommensurate with expenditures already being devoted to nuclear power at that time. During the mid-1960s AECL research expenditures were running about $60 million per year, so that almost two years' research funding would have been placed at risk by entry into the United States. The firm would have needed to advance about $37 million per year over six or seven years to complete two 500-MW reactors in the United States at its own risk. Whether this sort of additional financing would have posed a problem for AECL is debatable. It certainly was a small amount considering the size of the potential market had the reactors been successful. Especially after turnkey reactors were no longer being sold, AECL would have been well placed to build a CANDU installation in the United States, had it been prepared to absorb the risk.

Ontario's Political Interests

To Ontario Hydro, the political advantage of assisting provincial goals must have outweighed any consideration of experimenting with light-water reactors. Even if CANDU's capital costs had turned out to be significantly higher than those required to purchase a light-water reactor, at nominal interest rates of between 3 and 5 per cent, the operating cost of a higher-priced reactor would hardly have been significant. Offsetting any premium for capital would have been the lower fueling cost for the CANDU reactor, which does not need enriched uranium. CANDU's operating costs are lower than those of a light-water reactor, even if both reactors perform to standard.

CANDU clearly offered Ontario an attractive political, if not economic, package. Foreign coal would have been displaced by Ontario uranium, while much of the manufacturing would have been domestic. Ontario Hydro was not interested in export sales. At the time, it was premature to plan for standardization in order to reduce costs. This possibility emerged only in the early 1970s. But even if increased sales volume might have promised somewhat lower costs, the then-low rate of interest used by Ontario Hydro in its decision making made such considerations largely superfluous.

While Ontario Hydro used rates as low as 3 per cent nominal in the mid-1960s, Électricité de France, for example, used a 9 per cent *real* rate, according to Vernon ([ed.], 1974). With real rates of interest that were fivefold higher, the French utility could not afford to disregard even minor differences in capital costs. It, therefore, resisted nuclear reactor programs until 1971 and then opted for a standard U.S. light-water reactor.

The focus on the Ontario market by AECL was the path of least resistance. Because Ontario Hydro used a low real rate to evaluate capital investments, nuclear power was a clear winner over coal, and any slight difference that might have emerged between the costs of light-water reactors and the CANDU was of secondary importance. The political advantage of the CANDU for Ontario was clear, especially since AECL would continue to cover the giant's share of the research and development costs.

For AECL the path of least resistance has not turned out well. By placing all of its eggs in one basket it has paid the price risked by any firm that pursues an under-diversified strategy. Ontario Hydro influenced the development structure of the producing sector, which suits a domestic utility interested in custom-built generating stations. This same structure is ill-suited for international competition and large-scale selling efforts. By not moving quickly to establish a strong position in international markets, which would have been made necessary in the absence of Ontario Hydro as a crutch, AECL missed the opportunity to make CANDU the standard reactor in world markets. Instead, AECL has ended up with the second best hand in an enormous poker game that promises little, if any, payoff.

5 Business Strategy in a Declining Market

It is easier to enter a new industry than it is to decide on when and how to leave it. During the 1960s, increased federal government financing certainly was defensible if not opportune. A handsome return was a strong possibility if not an anticipation. The international market for nuclear reactors was reputed to be on the verge of booming. In the mid-1960s, the rapidly increasing rate of reactor sales by U.S. producers conveyed the impression that nuclear power was even then cheaper than coal-generated power. Even if coal still remained cheaper, surely in time, as nuclear reactor manufacturers and operators gained both additional experience and the learning that goes with it, coal would decline as a rival. Nuclear costs would continue to drop, but since coal-fired generation of electricity was a mature technology, the learning curve was flat and the cost of production would stabilize. Indeed, U.S. environmental legislation threatened an appreciable rise in the cost of coal before the end of the decade. Consequently, utilities had every reason to order nuclear power stations if only to gain the experience needed.

Though rival producers were numerous, the British and the French nuclear programs seemed to be stalled, and the German program was slow off the mark. U.S. producers seemed to have all the business they could handle at home, but even U.S. nuclear reactors were as yet untried. No one had as yet built a large light-water reactor, nor had they demonstrated its capabilities in the operating environment of a utility. The CANDU had already been selected by Ontario Hydro, which had had the option to choose a light-water reactor instead. Ontario Hydro officials told the writer that they made price comparisons at the time and CANDU was favoured. For AECL the Ontario Hydro decision promised market growth sufficient in Ontario alone to sustain an efficient scale reactor industry and to recover R&D costs. The future for CANDU seemed assured.

The rosy picture described above disappeared from sight at least a decade ago. Nonetheless, government financial support has continued to grow, though in real terms it peaked in 1973-74. But even though poor prospects have been evident for the CANDU for a decade, no clear-cut strategy has been settled upon. If there is a deliberate strategy, it is to plod on in the expectation that the odd reactor order will be forthcoming over the next decade and that the market will rebound in the late 1990s.

The phasing-out of an industry like the nuclear reactor business is not easy to implement. Work on reactors still under construction will continue for another six or seven years, and the infrastructure needed to maintain those reactors will be in demand for another 40 years. The decision for AECL to withdraw from the industry may not mean much more than scaling down its operations, reducing R&D budgets, and halting any major efforts to design improved reactors of the CANDU, or any other, type. In these circumstances, withdrawal from the nuclear reactor business need not be accompanied by a dramatic announcement. A shift of AECL's research efforts into nuclear waste disposal or a shift to components for "light-water" reactors or to other product lines would indicate withdrawal from the CANDU reactor business. Since a large part of AECL's R&D effort takes the form of overhead needed to maintain the stock of CANDU reactors presently in service or about to be commissioned, withdrawal from actively developing and marketing the CANDU may not be accompanied by a dramatic announcement. Withdrawal may lead Ontario Hydro into integrating those parts of AECL it deems necessary to maintain its reactors, and this could facilitate the paring-down of Canada's overall commitment to sustaining this apparently declining industry.

Dimensions of the Declining Demand for Nuclear Reactors

What are the near and longer-term prospects for nuclear power in general, and for the CANDU in particular? Much of the market forecasting reported here is from Evans and Hope (1983) and dates back to 1983. Table 5-1 suggests that total world-installed capacity will, at most, rise by 400 GW between the years 1985 and 2000. The more pessimistic prediction is for 200 GW. Since most of the installed capacity to be in place by 1990 will already have been ordered, the scope for new orders over the next decade is between 163 and 365 GW. If Canada were to retain a 5 per cent share of world markets, it would receive orders for between 8 and 18 GW over the next 15 years. At the low end, this amounts to about nine 850-MW reactors; at the high end, twenty-one.

But if the Evans and Hope (1983) estimates for Canada were at all a guide to the accuracy of their estimates for

Table 5-1

The Evolving Pattern of Nuclear Capacity Projections to 1985 and 1990

	Data source	Year of projection	Projected capacity 1985	1990
			(GW)	
North America	(1)	1972	295	539
	(2)	1975	223	426
	(3)	1977	125–157	214–287
	(4)	1979	112–134	177–214
	(5)	1980	96–119	138–156
	(Evans & Hope)	1983	84-105	113–135
Western Europe	(1)	1972	184	373
	(2)	1975	165–212	264–380
	(3)	1977	107–146	195–273
	(4)	1979	100–113	166–209
	(5)	1980	94–94	142–157
	(Evans & Hope)	1983	81–95	109–127
OECD Pacific	(1)	1972	63	106
	(2)	1975	49	85
	(3)	1977	27–40	50–80
	(4)	1979	26–33	45–60
	(5)	1980	28–30	51–53
	(Evans & Hope)	1983	20–23	27–33
Developing world	(1)	1972	25	50
	(2)	1975	46	114
	(3)	1977	19–25	45–60
	(4)	1979	19–23	45–50
	(5)	1980	14	30–33
	(Evans & Hope)	1983	10–15	19–23
WOCA	(1)	1972	567	1,068
	(2)	1975	479–530	875–1,004
	(3)	1977	278–368	504–700
	(4)	1979	257–303	434–534
	(5)	1980	232–258	361–399
	(Evans & Hope)	1983	194–238	268–331

SOURCE Nigel Evans and Chris Hope, *Nuclear Power: Futures, Costs and Benefits* (Cambridge, Mass.: Cambridge University Press, 1983), p. 10.

other countries, their estimates seem to be rather high. In Canada, after the Darlington plant has been completed in 1992, there will be 15 GW installed. If Evans and Hope were right about the level of installed capacity for the year 2000, between 3 and 8 GW more capacity is all that will be demanded before 1995. Today, surely the lower bound is closer to being a mean value of what is to be expected. Canadian orders for the CANDU will only follow if utilities sell surplus power from nuclear and conventional sources to U.S. utilities. This possibility bears the status of a hope rather than a prospect.

There is still worse news for the CANDU in the Evans and Hope data collected in Table 5-2. Countries like Argentina, Egypt, and Mexico, where we have a toehold, will not be major buyers. Indeed, demand will be modest in all non-OECD countries in the non-communist world: between 18 and 59 GW for the group, accounted for largely by demand from India, Korea, Taiwan, Brazil, and South Africa. Canada's best bet is for orders from Korea. (This hope has recently been dashed as Korea has rejected a bid from AECL in favour of further reliance on light-water reactors.) Keeping in mind the complicated Roumanian "sale" and prospective sales in Turkey, other Canadian sales will need to be in Eastern Europe or China. These markets remain small, and competition is intense for sales into those markets. France, for instance, has the capacity to sell between six and eight light-water reactors each

Table 5-2

Net-Installed Nuclear Capacity, by Country, Actual and Estimates for Selected Years, 1978-2000

			1985		1990		2000	
	1978	1982	Low	High	Low	High	Low	High
				(GW)				
Canada	5.5	7.0	9.0	10.1	11.6	13.3	18	23
United States	55	63	75	95	101	135	130	180
Austria	–	–	–	–	–	–	–	0.7
Belgium	1.7	3.5	4.5	5.5	5.5	5.5	5.5	8
Finland	0.4	2.2	2.2	2.2	2.2	2.2	3	4
France	4.6	23.2	35	40	50	56	70	90
Germany	5.6	9.8	12.6	16	19	23	28	40
Italy	1.4	1.3	1.3	1.3	2	3	7	12
Netherlands	0.5	0.5	0.5	0.5	0.5	0.5	0	3
Spain	1	2	5	7.5	7.5	11.5	12.5	20
Sweden	3.7	7.4	7.4	9.5	9.5	9.5	7	12
Switzerland	1	2	3	3	3	4	4	5
United Kingdom	5.8	5.8	9	9	10	11.5	10	17
Other Western European countries	–	–	–	–	–	–	3	10
Japan	11	17	20	23	27	33	60	95
Australia and New Zealand	–	–	–	–	–	–	–	2
OPEC countries	–	–	–	–	–	–	–	2
Argentina	0.4	0.4	1.0	1.0	1.7	1.7	2.7	3.7
Brazil	–	0.6	0.6	0.6	2	3	4.5	7
Egypt	–	–	–	–	–	–	2	5
India	0.6	0.8	1.3	1.5	1.7	2.6	7	10
Korea	0.6	0.6	1.8	3.6	5.4	7.2	11	18
Mexico	–	–	–	1.3	1.3	1.3	3	7
Phillippines	–	–	–	0.6	0.6	0.6	0.6	1.2
South Africa	–	–	1.8	1.8	1.8	1.8	3	6
Taiwan	0.6	3.1	3.1	4.9	4.9	4.9	7.5	14
Other non-developed countries	–	–	–	–	–	–	2	7
Total non-communist world	99	150	194	238	268	331	401	603

SOURCE Evans and Hope, *Nuclear Power: Futures, Costs and Benefits* (1983), p. 11.

year, since it has scaled down its domestic building program. (The *Globe and Mail*, November 19, 1984, p. b3, reported that Électricité de France would order only one plant in 1985 and 1986.) The French are reported to be able to undersell AECL by about 30 per cent, though it is unclear whether this figure includes the heavy-water charge for the CANDU reactor. Lower operating costs help the CANDU; whether they help enough to overcome the initial disadvantage, however, is uncertain. Nor should the U.S. industry be overlooked as a competitor. Though much maligned because of uncontrollable cost increases, some U.S. reactors have been built at a cost as low as, if not lower than, that reported for the French reactors. At the moment, GE is seeking approval of a sixth-generation, boiling-water reactor, which it hopes to market largely offshore. Keeping in mind the sort of rivalry that CANDU faces, winning 10 per cent of the market would be a considerable achievement, amounting to between 1.8 and 5.9 GW over a 10-year period.

Other forecasts are even less hopeful. Westinghouse recently forecast world demand outside captive markets like France, Canada, and Eastern Europe at only twenty-four 1200-MW reactors up to the year 2000. If Westinghouse is right, CANDU's 5 per cent share should result in, at most, two orders for 850-MW reactors from overseas ("Westinghouse Expects Nuclear Power Revival," *Globe and Mail*, Report on Business, October 9, 1984). That number is far below the number of reactor orders predicted by Secor Inc. in 1981 in Lortie and Schweitzer (1981). Secor Inc. anticipated sales of 32 GW in the year 2000.

Secor Inc. extrapolated demand for the period 2000 to 2020 (see Tables 4-6 and 5-3) Demand is expected to be three times greater than it was during the 20 years from 1980 to 2000. The tripling of the level of demand for the period 2000 through 2020 was borrowed from the International Fuel Cycle Evaluation. How good are these estimates? It would be difficult even to offer a guess. The market is expected to rebound because the present stock of electric-generating capacity has accumulated rapidly since the war. Even if the use of electric power should continue to grow more slowly than in earlier decades, replacement demand should still support the market. The present stock of power stations in the United States has an average age of 15 years; even with a life expectancy of 50 years, about 100 GW will be ordered for replacement purposes alone before the end of the century (Luce 1983). Increased load growth at a modest 1.5 per cent annually would stimulate demand for another 62 GW. If growth returns to a modest 3.4 per cent on a long-term basis (just half the 40-year average of 7 per cent), then 340 GW of extra capacity will be needed. Of course, not all the demand will necessarily be for nuclear reactors. The economics of coal vs. uranium has a lot to do with the decision to build a nuclear power station. In addition to these considerations, it is quite extraordinary that in the United States fully 25 per cent of installed electricity-generating capacity still uses oil or natural gas. This reflects the low price of oil and gas before 1973. Finally, many nuclear reactors built and commissioned in the mid-1970s will be phased out about the year 2010. Replacement installations will be ordered at the end of the century. Construction of power stations in other industrial countries has followed a similar pattern. Furthermore, since until 1973 oil and natural gas were often a lower-cost fuel than coal, numerous oil- and gas-fuelled stations remain to be replaced.

Upon analysis, the U.S. market remains the most promising for Canada; there, an enormous aging and expensive stock of generating capacity will be replaced during the final years of this century and in the early decades of the next century. But it is also in the United States, where coal is abundant and nuclear reactor manufacturing capacity is surplus, that CANDU continues to face an uphill climb.

Table 5-3

Forecasts for Nuclear Reactor Orders in Ontario Compared with World Market to Year 2000

	Installed capacity in the year 2000	
	World market	Ontario*
	(GW)	
1974	4,000†	
1977	1,543‡	80.0
1978	1,400‡	50.0
1981	800‡	28.0
1982		16.7

* C. A. Hooker et al., *Energy and the Quality of Life: Understanding Energy Policy* (Toronto: University of Toronto Press, 1981), p. 55.

† According to *An Energy Strategy for Canada* (Ottawa: Queen's Printer, 1976), p. 68.

‡ Lortie and Schweitzer, *A Strategy for the Development and Strengthening of the Canadian Nuclear Industry* (1981), various pages.

Competing Reactors

A decision to withdraw from the research, design, and demonstration of projects for improved CANDU reactors and competing reactor concepts is equivalent to exiting the industry. If these activities are not sustained at some reasonable minimum level over the next decade or two, other reactor designs will pre-empt any hope of a market for the CANDU. The experience and learning curves are real for nuclear reactors and their operating companies. Furthermore, light-water reactors will be continuously improved, and new reactor designs now on the drawing board or at the demonstration stage may become commercially attractive (see Weinberg and Spiewak 1984; Gould 1984; Wakstein 1978). Unless CANDU and AECL keep pace, it is conceivable that even Ontario Hydro will turn to foreign producers and designs for the next generation of Canadian reactors. Nor is it out of the question that improved desulfurization technologies will not make coal a still formidable rival to uranium for power generation.

The Japanese Ministry of International Trade and Industry (MITI) is co-ordinating a national program that will bring together Westinghouse, General Electric, Japanese nuclear reactor vendors, and Japanese utilities to design advanced light-water designs (see, also, Marcus 1983; Lester 1983; "Westinghouse/Mitsubishi: Inbreeding," *The Economist* 1982). In the United States, MIT has an active research program called "The Light-Water Innovation Project" (Golay 1984). The Swedes are studying a modified light-water reactor called PIUS, standing for "Process Inherent Ultimate Safety." This design is intended to give one week's passive protection from a loss of coolant to the core. At Three-Mile Island melting of the core began within two minutes of the loss of coolant (Freeman 1983).

Germany is presently demonstrating a 300-MW, high-temperature, gas-cooled reactor called a "pebble-bed" type of reactor. In the United States, Gas-Cooled Reactors Associates, a company owned by 30 utilities, is pursuing the development of a high-temperature, gas-cooled reactor (HTGR). Lidsky (1984) reported that a group of professors at MIT believe that the HTGR, cooled with helium, is a better "mousetrap." Lidsky foresees HTGR units being built in a factory. Each 100-MW reactor would be transported by truck to the power station site. Any economic loss resulting from the small scale of each unit would be compensated for by the advantages of standardized *serial factory production*, including a reduction in difficult to control on-site cases function costs. Quality control would be far easier, and the vendor would be able to sell reactor modules at predetermined prices. Furthermore, the modular arrangement would permit utilities to match their generating capacity more closely to load requirements and would reduce the severity of the effect of an accident. It is conceivable that a module could breakdown but the remainder of the power station stay in service. Apart from those advantages, the HTGR would be intrinsically safer, and loss of coolant would not result in a meltdown for several hours. The pebble-bed reactor is safer still.

The above options, which are now on the horizon, are just an example of the research and development work that is underway. Westinghouse and General Electric remain active. "Fast-breeder" programs are progressing, with France, Germany, and the United Kingdom having recently announced plans to build three new reactors (see Collingridge 1984*a*; Chow 1977; Dickson 1982, 1984; Marshall 1982; Young 1984; Cochran 1974; United States, "Analysis of ... Clinch River breeder reactor cost estimates" 1982; "A breeder reactor that may melt away," *Business Week* 1982; "American fast breeder faces a sterile future," *New Scientist* 1982). "Fusion" research continues as well. Nevertheless, the fairly conventional fission reactors remain the front runners for commercial uses, because the price of uranium remains low and supplies are abundant. The longer-than-expected life of the fission reactor is reflected in the willingness of countries and companies to invest in new and improved designs.

The CANDU will certainly not have the field to itself in 10 years or so, when the market is expected to revive. Is a new round of public investment warranted, given the future prospects for CANDU sales? That is the key question for the government, because without some effort to keep up, whether the market revives or not the CANDU will not be a valuable technology. But before a decision is made to invest, the prospects for the revival of sales ought to be examined. Making optimistic forecasts for the future of the nuclear reactor industry in Canada and elsewhere has had a long track record of failure. In the following few sections we shall look at AECL's prospective markets.

Coal vs. Uranium: Is Nuclear Power Competitive?

Anyone forecasting the future of the nuclear reactor market for the CANDU but also must assess not only the strength of competing reactor designers but also the future competitiveness of coal as a fuel for generating electricity. Whatever reactor design is chosen, coal is uranium's closest rival for generating base-load power. The recovery of the nuclear reactor market is tied to the cost-effectiveness of coal for generating power. During the 1960s and up until 1975, nuclear power was believed to be far cheaper than coal power. This belief has since evaporated in the United States. The explosive rise in capital costs (13 per cent per annum) and the poorer-than-expected performance of nuclear power stations already in service have forced a re-evaluation.

Ontario Hydro's Analysis

Elsewhere in the world, including Canada, nuclear power remains more popular. In 1981, for instance, Ontario Hydro reported that the lifetime costs of equivalent-sized stations were 2.14 times higher for coal than for the CANDU (Ontario Hydro, Report #62058, 1981, p. 4). This high figure was reduced to just 1.46 in a later study (Ontario Hydro, Report #620SP, December 1982). Both studies measured the value as of 1995 of all costs incurred during construction and throughout the 40-year lifetime of the plant, based on present values. These results are also based upon the assumption that the coal and nuclear plants will both operate at a capacity of 80 per cent. But even if the capacity levels should fall, which would favour the coal plant since less fuelling would be needed, the nuclear option maintains a large advantage over coal.

OECD's Analysis

An OECD study (1983*b*) gives nuclear power an advantage of between 29 and 75 per cent. In the central United States (the Chicago region), nuclear and coal costs just break even. At a real discount rate of 10 per cent, the advantage of nuclear power over coal in Europe reportedly varies between 9 and 31 per cent except for France, where the advantage is 50 per cent. In the United States, nuclear power costs 20 per cent more than coal. For some reason, in Canada nuclear costs maintain a 14 per cent advantage over coal, even at a 10 per cent real rate. These comparisons are based on 1981 figures and may be out of date. The dynamics of these forecasts are evident from the two Ontario studies, which in one short year saw the advantage of nuclear power almost halved. The OECD study based its Canadian result on the 1981 Ontario Hydro study, which reported capital costs of a nuclear plant to be just 109 per cent of a coal-fired plant. In December 1983, Ontario Hydro increased its estimate to 134 per cent. This upward adjustment to the OECD data would lead to coal being a more attractive option in Canada.

As we have seen, the Ontario Hydro study (Report #6205, December 1982) gave nuclear power a substantial advantage over coal. Assuming a capacity factor of 80 per cent for both, the present value at the time of commission for all costs was 46 per cent higher for coal than for nuclear power. Even with an average capacity factor of 60 per cent, the advantage was 33 per cent.

How can Ontario Hydro studies assign to nuclear power such an extraordinary advantage, while the OECD study, which was based upon the same data, presents quite a different picture? The difference is due to Ontario Hydro having used a real rate of discount of about 2 per cent in 1981, whereas the OECD required that the calculations be made using both a 5 and 10 per cent real rate. With a 5 per cent real rate, the nuclear advantage dropped from 114 to 42 per cent in central Canada (OECD 1983, p. 26). That is still on the high side compared with most European countries. It is, of course, far closer to the results in Ontario Hydro's 1982 study. This should be no surprise, since in 1982 Ontario Hydro used a real rate of 4.5 per cent.[1]

The OECD study itself leaves many unanswered questions and is most revealing of the influence of interest groups in politics. German coal, for instance, is priced at 85.6 ECU/tonne (as of January 1981), compared with imported coal priced at 51.4 ECU/tonne. Nevertheless, German calculations giving nuclear power an advantage are based on the use of domestic coal for 50 per cent of requirements. Similarly, in the United Kingdom coal is priced at 72.0 ECU/tonne, whereas in France and Italy it is only 51.2 and 49.8 ECU/tonne, respectively. Nuclear's advantage in Germany and the United Kingdom depends significantly upon continued artificial pricing of coal for additional coal-fired plants. This is truly ironical, even if politically realistic. Nuclear stations may replace coal stations because domestic coal prices are being maintained in the United Kingdom and Germany at a premium that is between 40 and 52 per cent above the international price, respectively.

It is not surprising that nuclear power should have an advantage over coal in the OECD study, given the high coal prices used and the reported cost of building coal generating stations. According to the study, it costs Europeans, for some reason, far more to build a coal station than it does Canadians. The British report a cost of 1,372 ECU/kW and the French 655 ECU/kW, even though both plants are without desulphurization equipment. The comparable Canadian cost with desulphurization (which adds about 20 per cent to the capital cost) is just 449 ECU/kW. Surely we are getting some questionable analysis on the cost of building coal-fired stations, which gives an overwhelming advantage to nuclear power. If OECD cost estimates are valid, then the nuclear advantage in Europe is due largely to distortions in the price of coal and the construction of coal-fired stations. On the other hand, if these estimates are simply padded, then we have every reason to question the veracity of reports that seem designed to give nuclear power an advantage over coal.

Most European countries predict that the price of coal will rise faster than uranium at a real rate of 2 per cent per annum. This, too, is a questionable assumption that contributes to finding that a coal-fired station is a poor choice.

The Ontario Hydro studies seem to be more reliable concerning the initial capital cost for constructing coal and nuclear stations than the figures provided for European countries in the OECD paper. Nevertheless, it is by no means clear that nuclear power has any advantage over coal, even in Ontario.

A U.S. Analysis

One is led to question Ontario Hydro's conclusions when one considers the comparable U.S. figures for Chicago. In the OECD study, despite all the apparent padding of coal costs, nuclear power just breaks even with coal at a 5 per cent real rate and falls behind coal, costing about 20 per cent more, at a 10 per cent real rate. Moreover, many other U.S. studies give coal a far greater advantage than 20 per cent. A recent study by Hellman and Hellman (1983) found that four major U.S. studies comparing the costs of nuclear power with those of coal overstated the advantage claimed for the former. The four studies gave nuclear power the edge, as follows – 1.60; 1.24; 1.15; and 1.06. Hellman and Hellman corrected the nuclear/coal cost ratios and all four studies favoured coal as follows – 0.78; 0.71; 0.57; and 0.50. Electricity generated from coal was as much as half the cost of electricity from nuclear power in two of the studies after Hellman's corrections.

Real Rates of Interest Used in Ontario Hydro's Analyses

Ontario Hydro (1982) favoured nuclear power over coal, despite a rise in the capital cost of a nuclear station, largely because it used the following nominal discount rates:

	(Per cent)
1982-85	17
1986-87	16
1988-99	15
1991-95	14
1996-2000	13
2000-	12

The real rate was assumed to be 4.5 per cent (p. 9), whereas in an earlier report (Ontario Hydro 1981) the real rate used was just 2 per cent. The later study assumed that the rate of inflation would range between 10 and 12 per cent to 1995 and that it would continue at 8.5 per cent to 2000 and then remain at 7.5 per cent for the rest of the 35-year life of the station.

A low-real interest rate, gives nuclear power a significant advantage. The advantage comes from its lower fuelling costs and higher capital costs. By contrast, inflation itself should not in principle affect the choice between nuclear and coal generation, unless the relative prices of coal and uranium are expected to change with inflation. If a high rate of inflation is anticipated, a utility that chooses to build a coal-fired generating station will save on borrowing costs an amount sufficient to pay for higher-priced coal in the future. This assumes that the anticipated rate of inflation is built into then current interest rates. If so, the additional interest expenditures due because of the higher initial cost of the nuclear station will offset the greater fuelling costs of the coal-fired station.

But inflation will not be neutral when the tax system does not correct for it. Because Ontario Hydro does not pay taxes, no distortion is introduced by using the book value for depreciation purposes throughout the life of the reactor. If depreciation charges in the early years were placed in a fund to earn interest, they would recover inflation costs and be sufficient to replace the plant at the end of the period. For private utilities, however, the corporate tax rate would introduce a serious distortion. With high inflation rates, straight-line depreciation leads to profits being overstated in the early years, thereby increasing tax expenditures. At the end of the period, the station could not be replaced from the accumulated funds generated by depreciation charges net of the additional tax.

This difference in tax treatment may help to explain why private U.S. utilities have turned away from nuclear power while Ontario Hydro continues to favour it. This point is worth more investigation because a decline of inflation, or a reform of corporate taxation, may lead to a revival of the demand for nuclear power by private U.S. utilities.

The Ontario Hydro study provides information about the sensitivity of the cost of producing electricity to altered assumptions about the relative prices of coal and uranium. For instance, if coal price escalation were 20 per cent below that which was forecast, the advantage of nuclear power, at an average capacity factor of 80, would drop to 17 from 46 per cent.

Thus two factors can have a significant influence on the measures of relative advantage of nuclear over coal. One is the real rate of interest, and the other is the forecast of the relative price of coal to uranium. Table 5-4 shows that Ontario Hydro is willing to spend about $1,127/kW in extra capacity (in 1995 dollars) to buy nuclear power rather than coal, hopefully to save about $6,373 (in 1995 dollars) in equivalent-year dollars. This certainly is a sound investment. But should inflation drop from 7.5 to 4.5 per cent and the cost of funds remain at 12 per cent, (an increase in the real rate by 3 percentage points) then the anticipated saving would fall to $3,195. If coal price escalation were to lag 2 percentage points behind that of uranium the advantage would be just $1,409.

Despite the above caveats, the Ontario Hydro study does indicate that nuclear power would seem to be a better investment in Ontario than is coal-generated power.

Energy, Mines and Resources Evaluations

A fairly recent government study (Canada, EMR 1981*b*) helped to place the Ontario Hydro study in context. Unlike the Hydro study, the one by Energy Mines and Resources calculated costs and benefits in "real" terms. The inflation rate was assumed to be zero, and uranium and coal prices were fixed at the 1978 level. At a 4 per cent real rate of discount and with 80 per cent average capacity, the nuclear advantage over coal was 170 per cent. At a 10 per cent real

Table 5-4

Hypothetical Cost Ratios of Coal to Nuclear Energy for Producing Electricity, Ontario Hydro (1995 Dollars)

	Costs per kw of output at 80 per cent capacity			
	Nuclear energy	Coal	Incremental cost of a coal plant	Ratio of coal to nuclear energy costs
	(Dollars)			
Capital cost	5,534	4,134	1,400	
Annual operating costs (excluding depreciation and financing charges)	224.24	576	(351)	
1. Present value of operating cost (1985 in 1995 dollars)	4,310	11,019		
Total cost	9,852	15,359	5,507	1.54
2. Present value of operating cost (1985 in 1995 dollars)	2,929	7,532		
Total cost	8,463	11,666	3,203	1.37
3. Present value of operating cost (1985 in 1995 dollars)	2,929	5,736		
Total cost	8,463	9,870	1,407	1.17

NOTE Assumptions for three cases:
1. Inflation is assumed to be 7.5 per cent and the nominal interest rate is 12 per cent.
2. Inflation is assumed to be 4.5 per cent and the nominal interest rate is 12 per cent.
3. The nominal interest rate is 12 per cent and the rate of increase of uranium prices is 4.5 per cent and of coal prices is 2 per cent.

SOURCE Calculated by author from data found in J.V.C. Fong; J. Basu Roy; G. N. Meehand; and G. F. McIntyre, *Cost Comparison of CANDU Nuclear and Coal-Fuelled Generating Stations*, Report #620 SP (Toronto: Ontario Hydro, 1982).

rate it dropped to 117 per cent. For some reason or other, this study failed to include the opportunity cost of capital during the period of construction. This would have added over $500 million for the nuclear option and just under $200 million for coal had a real rate of 10 per cent been applied.

It may seem surprising that nothing more definitive can be said about the relative costs of nuclear power and coal. Certainly during the boom years of the late 1960s and early 1970s little was known about the true costs of a nuclear reactor, about the level of capacity that would be operational, or even about the expected life of a station. More information is now available on the reliability of nuclear stations and their operating costs; any estimate of the relative advantage or disadvantage of nuclear power over coal is dependent upon estimates of real interest rates and the relative prices of coal and uranium over a 50-year period. As a result, we are forced to agree with the conclusion of Bupp and Derian (1978). After extensive analysis of the data on this subject they concluded that "it is literally impossible to make a determinate economic case either for or against nuclear power" (p. 162).

6 Cost/Benefit Analysis: Past and Future

This study has found that because the demand for electricity, and thus the derived demand for nuclear reactors, has fallen far below the expectations held with conviction before 1975, the CANDU has been expensive for Canada. In this chapter it is estimated just how costly it has been. But sunk costs are behind us. The key question now is whether or not Canada should undertake any additional investment and through what corporate form. If further investment is not made, other reactor technologies will pre-empt the CANDU. In the preceding chapter it was shown that there is virtually no market for nuclear reactors anticipated for at least a decade. After that, the market may revive, especially in the United States. After looking at the dimensions of past performance some tentative suggestions are made about the minimum investment that will sustain the CANDU until 1995. The possibility of earning a return on this investment is explored.

Estimated R&D Costs of the CANDU System

The value, as of 1981, of all R&D expenditures for the CANDU reactor systems to the end of 1982 totalled $14 billion (in 1981 dollars), based on real opportunity costs of 7.5 per cent. Since 1982, R&D expenditures have continued at a level of about $150 million/year, which would seem sufficient to maintain the 15 GW of installed nuclear capacity to be in place by 1992. At a real rate of 7.5 per cent, the present value of the future R&D expenditure flow is $2 billion. Thus, as of 1981, the total

Table 6-1

Federal Expenditures to Finance Heavy-Water Plant Construction and Heavy-Water Production*

	Heavy-water plants				
	Bruce	Glace Bay	Port Hawkesbury	La Prade	Heavy-water inventory
			($ Millions)		
1978-79	–6.29	8.3†	9.0	102.5	30
1977-78	–5.85		12.0	56.5	2.25
1976-77	–5.42	23.0	3.0	37.0	5
1975-76	–1.30	33.5	35.0	69.0	15
1974-75	–	54.0		31.0	–17.5
1973-74	–	55.0			–4.1
1972-73	20.0	18.0			11.0
1971-72	68.0				10.6
1970-71	62.0				–
1969-70	25.0				10.0
1968-69					
Total principal outstanding	156.14	191.8	59.0	296.0	62.25
Uncollected capitalized interest	57.094	72.9	NYC‡	NYC‡	–
Total amount due	213.23	264.7			62.25

* The amount shown reflects total advances, net of repayments on principal; repayments on interest are included in Table 9 in the source given below.
† The amount includes a $3.3-million loan to finance 1978 instalment payment on Glace Bay purchase.
‡ Not yet capitalized (NYC).
SOURCE Canada, Department of Energy, Mines and Resources, *Nuclear Policy Review: Background Papers* (1981), p. 319.

costs "sunk in" the program amounted to about $16 billion (in 1981 dollars). This figure makes no allowance for additional write-offs for prototype reactors and heavy-water plant construction (see Tables 6-1, 6-2, and 6-3). Excluding interest and not adjusting for inflation, heavy-water plant subsidies from the federal treasury totalled $546 million (excluding the Bruce station, which was purchased from AECL by Ontario Hydro). As of 1981, those additional expenditures added $2 billion to the $16 billion spent on R&D. Altogether, then, the federal government has spent the equivalent of $18 billion (in 1981 dollars) on the CANDU program.

It is true that part of AECL's R&D effort might have been in support of non-commercial projects, or projects other than the CANDU. Professor Meneley, in a private communication, suggests that as much as 40 per cent of the R&D expenditures should reasonably be apportioned for non-CANDU projects. I think this exaggerates the proportion not related to nuclear power projects, but AECL has not offered any precise fraction to use. In the absence of a detailed study on the question, we are left with little choice but to make a conservative assumption. For the sake of argument then, in what follows $6 billion is being allocated to research for non-commercial and non-reactor programs. This is about 33 1/3 per cent of the total R&D budget. Though somewhat less than Professor Meneley's figure it is considerably higher than I would guess is the true figure. The total cost of the R&D effort is then taken to be $12 billion (in 1981 dollars), and not $18 billion.

Even on the basis of this conservative assumption, the average R&D costs per kilowatt hour of installed capacity in Canada have turned out to be high. Until completion of the Darlington plant the average will be $1,053/kW; that will drop to $809/kW upon completion. It should be kept in mind that these average figures include a real interest rate of 7.5 per cent from the year spent, forward and

Table 6-2

Federal Financing of Commercial Nuclear Reactors in Canada: Cash Outflows, Repayments, and Amounts Outstanding

	Pickering A units 1 and 2	Gentilly II	Point Lepreau
		($ Millions)	
1978-79	–	–	100.0
1977-78	–		60.4
1976-77	–15.798	41.0	44.1
1975-76	–9.00	59.0	30.0
1974-75	–5.490	31.0	
1973-74	–6.909	20.0	
1972-73	10.057		
1971-72	20.052		
1970-71	28.0		
1969-70	22.0		
1968-69	19.0		
1967-68	9.0		
1966-67	6.0		
1965-66	2.4		
Total principal outstanding	–	151.0	234.5
Uncollected capitalized interest	–	–	NYC‡
Total amounts outstanding	–*†	151.0	–§

* Outstanding principal of $79.312 million converted to Canadian equity in AECL in 1977-78.
† Uncollected interest of $38.6 million forgiven in 1977-78.
‡ Not yet capitalized (NYC).
§ Drawdown incomplete.
SOURCE Canada, Department of Energy, Mines and Resources, *Nuclear Policy Review: Background Papers* (1981), p. 312.

Table 6-3

Federal Government Expenditures on Prototype Reactors

	Douglas Point	Gentilly I
	($ Millions)	
1977-78		5.87
1976-77		
1975-76		
1974-75		
1973-74		
1972-73		
1971-72		4.7
1970-71		19.0
1969-70		21.0
1968-69		22.0
1967-68	4.000	12.5
1966-67	18.275	2.5
1965-66	5.812	
1964-65	11.027	
1963-64	12.000	
1962-63	12.556	
1961-62	5.075	
1960-61	1.200	
Total	69.945	87.570

SOURCE Canada, Department of Energy, Mines and Resources, *Nuclear Policy Review : Background Papers* (1981), p. 308.

backward to 1981. They are calculated by dividing $12 billion by the number of kilowatts of installed capacity.

To put these figures in perspective, it is worth recalling that the capital cost of CANDU reactors to Ontario Hydro is between $1,300 and $1,700 per kilowatt. If Ontario Hydro were charged the full cost of the R&D per kilowatt, the capital cost of a nuclear reactor would rise by at least 50 per cent. Except at real interest rates of near zero per cent, a cost-minimizing Ontario Hydro would certainly have selected coal in every instance.[1]

It was not planned to work out that way. Had expectations for the growth of demand for electricity been fulfilled, by 1977 average R&D costs would have been just $546/kW, falling to $250/kW by 1990, $133/kW in 2000, and $96/kW in 2008. Had AECL succeeded in making a sizeable number of sales offshore, the average R&D cost per kilowatt of Ontario Hydro's reactors would have fallen still further. Herein, the reactors built abroad are disregarded. There are two reasons for that. First, it was argued above that foreign sales were not part of the initial plan for CANDU's development; sales abroad became a priority only after 1970. Even then, sales abroad served a political, as much as an economic, purpose. Second, all sales lost money on a realistic accounting basis.

Ontario Hydro and AECL would almost certainly respond to this data by replying that all nuclear reactor manufacturers have benefited from government research and development programs. The fact is on target, but what inference is to be drawn from it? It was confirmed by a U.S. report that nuclear power in the United States would cost between 1.5 and 2.0 times more in the absence of government R&D expenditures (U.S. Department of Energy 1982). If the inference is that without the subsidy from the federal government, Ontario Hydro would have bought U.S. reactors or relied instead upon coal-fired stations, the writer of course agrees; but that is just the point. Ontario Hydro can always import nuclear technology; Canada would not have been deprived of nuclear power had the CANDU not been developed. Its full development cost must therefore be compared with the net benefit to Ontario Hydro of using the next best alternative.

Benefits and Costs to Ontario Hydro of CANDU Compared to Coal

The benefit to Ontario Hydro having selected the CANDU is difficult to determine. Energy, Mines and Resources Canada estimated $1 billion as the value in 1981 of the fuelling and operating savings to be gained from the use of an 850-MW reactor instead of a coal-fired generating station (Canada, EMR 1981*b*, Table 14, p. 54). The present value of the benefit stream, in the year the nuclear plant goes into operation, is $1,176/kW in 1981 dollars. This fixes the benefit against which to compare the incremental cost of the nuclear station.

It costs Ontario Hydro between $294/kW and $471/kW more for a nuclear plant. The first figure came from Ontario Hydro (Report #620SP, 1982, Table 1), adjusted for inflation; the second, from Canada (Canada, EMR 1981*b*, pp. 29-48). The EMR study excluded coal-desulfurization equipment ($114/kW) and the interest cost incurred during construction ($114.5 million for coal and $381.9 million for nuclear power, with both figures calculated at a real rate of 7.5 per cent). It also used the variable cost rather than the full cost of heavy water. In addition to making adjustments to account for these three omissions, the figures were converted by this writer from 1978 to 1981 dollars, using the consumer price index.

Ontario Hydro, by selecting nuclear power instead of coal, spends between $300/kW and $470/kW more for the initial capital investment, and it anticipates benefits of $1176/kW. Its net saving is between $706/kW and $876/kW (in 1981 dollars). Since R&D costs are not charged to Ontario Hydro and are sunk in any event, it is no surprise that Ontario Hydro prefers the CANDU to coal. It is important to recall that in the preceeding chapter we pointed out that the calculation of the cost advantages of coal over uranium is sensitive to assumptions about the relative rates of increase of coal and uranium prices, as well as the real interest rate. The reader may note that the cost/benefit for CANDU vs. coal differs here from that reported in the last chapter. The difference is due to the fact that here we use the EMR data and adjust for omissions.

If we take for granted that the political process would not have allowed Ontario to source offshore the reactor component of a nuclear generating station, then the CANDU has saved Ontario Hydro about $800/kW, and the Canadian government has spent for R&D an amount that will translate into $808/kW once Darlington is on stream. This has not been a wonderful investment for the Canadian government, but if the transfer to Ontario is taken into account, the program is just breaking even. Had electricity demand continued to grow at nearly the rate expected, the value of the CANDU might have proven itself.

Benefits and Costs to Ontario Hydro of CANDU Over Light-Water Reactors

The next best alternative to the CANDU may not be coal; it may be a light-water reactor. Ontario Hydro estimates the cost of four 850-MW CANDU reactors at $4,427/kW each, in 1995 dollars (or the equivalent of $1,075/kW in 1981 dollars); other estimates range as high as $1,700/kW (in 1981 dollars). The range of costs for light-water reactors for different reactor projects is wider than for Canadian CANDU reactors. Moreover, U.S. cost figures include the interest cost during construction, calculated at the average cost of the firm's capital. Since U.S. firms add this amount to their rate base when the plant is commissioned, they have every incentive to enter the interest costs at a high rate. For many nuclear reactor programs in the United States, the imputed interest cost totals 40 per cent of the total capital cost. Even including these items the lowest-cost reactors cost as little as $960/kW (US), whereas some reactors, because of poor management and faulty construction, will cost over $5,000/kW by the time they are finished.

On average, light-water reactors are thought to cost about the same amount as the dry costs of a CANDU reactor (about $1,350/kW in 1981 dollars). The initial heavy-water charge makes the CANDU more expensive than a light-water reactor.

The benefit side of the calculation is due to EMR. Energy, Mines and Resources estimates the present value of the savings favouring the CANDU at $232 million (at 7.5 per cent) for an 850-MW CANDU reactor (Canada, EMR 1982, p. 54). The benefit is derived from the lower operating costs of the CANDU since it does not use enriched uranium. It also assumes that the operating experience of the CANDU is better than that of the light-water reactor. This assumption, though true for the average U.S. light-water reactor, is not true of the best ones. Since the capacity is related to the quality of the utility operating the power station, one ought to assume that Ontario Hydro would build and operate light-water reactors to the same high standards as the CANDU. In this connection, the most successful U.S. utility in the nuclear business is Duke Power. This utility builds and operates its own station, much as Ontario Hydro does.

On the basis of average figures, an optimistic measure of the net benefit to Ontario is $41/kW after the cost of the heavy-water charge is accounted for. The benefit is $278/kW from lower operating and fuelling costs, before capital costs are deducted. A significant component of capital cost is the cost of heavy water which for an 850-MW reactor is given by Energy, Mines and Resources (1981*b*, p. 34) to be $155.5 million (1978 dollars). This figure is below the 20 per cent of dry costs often reported to be the cost of the initial heavy-water charge. It is based on a price of $203/kilogram heavy water, which is considerably below some estimates that run as high as $330/kilogram. Of course, at the moment the opportunity cost of heavy water is virtually zero since Canada has an enormous stock of heavy water. But the measurements offered here prodvide a retrospective of the cost of the CANDU program compared with non-CANDU alternative sources of energy. In these circumstances, it is appropriate to count the full cost (capital and operating) of heavy-water production as a charge to the CANDU program. With the full costs of heavy water included, Ontario Hydro's incremental capital cost for one kilowatt hour of additional capacity (relative to the alternative of a light-water reactor) is $237/kW. The average cost to Canada in R&D expenditures is $1,053/kW before Darlington comes on stream and $809/kW afterwards. Since after Darlington, Ontario will have just under 15 GW of nuclear-generating capacity, the benefit from CANDU to Ontario totals just $615 million (in 1981 dollars), and the cost to the Canadian government is about $12 billion (in 1981 dollars). These findings are set out in Table 6-4 (in units of kilowatts per hour of installed capacity).

Table 6-4

Costs and Benefits to Ontario and Canada from the CANDU Reactor Program Relative to Coal and Light-Water Generated Electricity (1981 Dollars per kilowatt Hour of Installed Capacity)

	Coal	Light water
1. R&D cost	809	809
2. Ontario Hydro's incremental cost of building a CANDU station	294-471	237
3. Incremental cost to Canada (R&D plus capital)	1,103-1,280	1,034
4. Benefit to Ontario from lower operating and fuelling costs	1,176	278
5. Net savings to Ontario (row 4 minus row 2)	882-705	41
6. Net savings (losses) to Canada (row 4 minus row 3)	73-(104)	(756)

Assuming that all federal costs are sunk, it would require about 80 GW of CANDU capacity to be installed before the sunk cost could be said to have been recovered in the sense that the present value of savings enjoyed over the next best alternative equals the full cost of the R&D effort. At the present time the most optimistic forecasters predict no more than 20 GW capacity in Canada by the year 2000. CANDU reactors sold abroad are not included in the above cost/benefit discussion because at commercial rates of finance, it is doubtful whether any sales to date have been profitable for Canada. The one operating reactor outside Ontario (the one in New Brunswick) should be added to this analysis; but since it has just recently come on stream, it is difficult to write as if the people of New Brunswick have already benefited from CANDU. In any event, adjustments to the findings reported here for Ontario would be minor.

The above cost/benefit analysis is relevant to the decision that the government must make in the near future about the CANDU's future. In the late 1950s, the government decided to invest many hundreds of millions of dollars in venture capital on the future of a new technology. The cost/benefit analysis indicates that the high hopes held for the venture have failed to materialize. The best that can be said for the economics of the CANDU is that it did stimulate research and development in Canada, and it allowed Canadians to participate in nuclear engineering research without leaving home.

CANDU's Future

At the time the CANDU project was initiated, the technology was in its infancy, but its market prospects seemed to be limitless. Today, the technology is reasonably well developed, but the market prospects are dim. The market has disappeared, and it is uncertain to what extent it may return after a decade. When the market recovers, fission could be on the verge of being pre-empted by fast-breeder and later fusion technologies. It is less certain still whether the CANDU will be competitive with the other classes of fission reactors on the market or under development. In the late 1950s the government established a mission-oriented firm with a technological imperative – make the CANDU a viable economic reactor. This seemed to be the right decision for the time. Since the domestic market was thought to be sufficiently large to sustain a viable manufacturing industry in Canada and the market was guaranteed to AECL, success on the technological front assured commercial success. Today the picture is quite different. Technological successes in research and development might help, but AECL's mandate is much broader. Over the next decade, it must position the CANDU and other improved CANDUs in world markets. The present marketing strategy of AECL will not sustain the CANDU through the next decade, nor will it turn CANDU into a serious rival to other producers. At the moment, CANDU relies on the domestic market and on certain developing countries. Most of the developing countries where Canada has some presence will not be buying many reactors. Some that may, like Korea, have both light-water and heavy-water reactors in operation and could easily play one vendor off against another. They have recently announced their intention to do more of the reactor manufacturing work at home (see "South Korea plans to keep nuclear work," *The Globe and Mail*, August 31, 1984, p. b4). All other developed countries have industries of their own and will be seeking to protect their home markets, while selling aggressively in foreign markets.

In the face, then, of a small potential market and determined rivals in world markets, the CANDU is boxed in. The domestic market will not, as it did in the 1950s, justify a major research and development program. Unless AECL aims at selling in foreign markets, it would be foolhardy to expend large sums to improve the CANDU. Without such expenditures, though, the CANDU is unlikely to even hold on to the domestic market; so

AECL's choices are limited. It either develops a marketing strategy that offers some hope of expanding the market for the CANDU, or it forms some sort of alliance with a foreign reactor developer. The first alternative requires a sizeable investment, which the writer argues below cannot be undertaken unless about $6 billion is spent over the next 10 years. The $6 billion figure is a ball-park "stab in the dark," but I think it helps to focus attention on the dimension of the problem. The second option – i.e., to seek an alliance with other developers – is less expensive. It offers less scope for profit should the market rebound and, against all odds, CANDU remains competitive 10 years from now. On the other hand, the second strategy may ensure that AECL's research abilities are put to effective use and that a Canadian reactor industry participates in the research and production of the next generation of Canadian nuclear reactors.

The reactor industry will certainly go through a shakeout over the next decade or two. Will the CANDU survive the restructuring of the international industry? The "go it alone" approach requires AECL to increase its research and development activity, and to develop "credibility" in world markets. To achieve credibility it needs to continue to sell during the present drought and to demonstrate a safety record and operating experience second to none. In the complex international market, even such achievements will not assure the CANDU's future. The truest test of the CANDU's credibility demands that the CANDU be licensed for construction in the United States.

CANDU in the U.S. Market

There is more to be gained than credibility for the CANDU among potential customers in developing countries. The best potential market for the CANDU outside Ontario is the U.S. market. Here, negotiations over free trade and access to the U.S. market should maintain access to that market for the CANDU. Similar efforts in Europe and Japan have less chance of success. Moreover, as reported above, around the turn of the century, the U.S. utilities are likely to be ordering between 150 GW and 400 GW of power-generating capacity.

It will be expensive to seek credibility for the CANDU. Research will need to be stepped up. More importantly, reactor orders will need to be won at concessionary prices or with AECL accepting most of the risk. The U.S. utilities are cautious about ordering nuclear reactors because their regulatory process for setting electricity rates makes it difficult for the utility to finance construction. A return to turnkey projects would do much to revitalize the market. The risk here is high, but that is part of what seeking credibility entails.

Financial Implications of Sustaining the CANDU Industry

Is there much chance of recovering the required investment? The writer's guess is that the enterprise is not worth considering without a willingness to commit some $4 billion between now and 1995. Since these expenditures will generate no cash flow until well after 1995, the opportunity cost of the $4 billion (at a 7.5 per cent real rate) is about $6 billion. Nor does this amount include the losses on normal so-called export financing guarantees and concessions. It is not useful to justify in detail so vaguely arrived at a figure as the $6 billion. The $400-million expenditure each year envisioned here is split between additional research, development, the demonstration of new concepts, and the large subsidies needed to gain a toehold in the U.S. market.

At the real rate of 7.5 per cent, break even is achieved when AECL earns a return of about $1 billion each year between 1995 and 2025. At an order rate of 4 GW (about five 850-MW reactors), sales would need to earn a premium of $250 per kilowatt (measured in today's dollars). This amount is about 15 per cent of the 1984 capital cost of one kilowatt of installed nuclear-generating capacity. This sort of premium can be earned if the market strengthens sufficiently and if, in the meantime, other nuclear reactor producers withdraw from the race. Unfortunately, other reactor producers, especially the Japanese, in a consortium with Westinghouse and General Electric, show no signs of withdrawing. Nor are the Germans or the French likely to exit. But it is conceivable that CANDU will succeed in lowering its capital costs to the point where its cost advantages on the operating side of the equation confer on it a 15 per cent advantage over other producers. This sort of premium will not be recovered in Third World markets, where all producer countries dump their products. This is one reason why every opportunity to establish a presence in the U.S. market is worth considering.

The premium required to break even falls as the volume of orders rises. It is not out of the question that orders could rise to three or four times the 4 GW per year suggested here. Certainly the investment is ill-advised if the most that one can expect is to break even. The purpose of the investment is to stay afloat in the expectation that market recovery will bring many more orders than 4 GW per year. But 4 GW is not an insignificant amount, and it is quite possible that even the level of 40 GW over 10 years will not be reached.

Other considerations weigh against the investment. A 7.5 per cent real rate hardly seems the sort of hurdle to use for an investment that carries with it so much risk. More importantly, the success of the investment depends upon AECL's prowess as a strong strategic marketer. The organizational study reported here does not give one the confidence that AECL has the orientation for this. AECL has reformed itself since 1978. Is there enough change to warrant undertaking a new challenge as daunting and risky as was the decision for a small country like Canada to pursue the CANDU in the first place? It will come as no surprise to any reader who has come this far in this paper that the writer has serious reservations as to whether a Crown corporation is the proper instrument for so large and risky a public investment.

The second strategy entails seeking partners, whether for CANDU or someone else's technology. Its main virtue is that it is likely less expensive than the first. It may allow AECL to participate in the commercialization of a technology that has a larger guaranteed market or greater credibility in the open market, or both. Where such a partner is to be found makes the option problematical. It is reported in the press, and Professor Meneley confirms that AECL is seeking such a relationship with the Japanese. Atomic Energy of Canada may not be valuable in the eyes of potential partners, given that no income can be anticipated for almost a decade. Moreover, there would be loss of prestige associated with the sale of AECL or its entry into a joint venture with an offshore producer. It would be easier if the partner were a government-owned producer. One can imagine the political outcry that would result from combining AECL with a U.S. multinational. Another virtue of this option is that if a partner cannot be found, there is every reason to question the wisdom of proceeding with the first option.

7 Conclusion

A Crown corporation has been found to be an unsuitable instrument for a new, technologically complex, high-risk industry when the corporation must achieve both recognition and scale by selling in an unprotected and disputed international market. When CANDU was first considered for commercialization, it was thought probable that the technology could be profitably exploited for the Canadian economy alone. Moreover, it was not yet clear that rival producers had a better "mousetrap" to offer. In those circumstances, the firm selected to develop the CANDU should properly have been, first and foremost, a "mission-oriented" research organization like NASA. But when exploitation of a technology depends upon success in an oligopolistic world-scale industry, government enterprises are at a disadvantage.

The public firm is weak because senior managers are unable to implement long-term market strategies. They are dominated by the firm's constituencies. The government, because it remains the sole source of finance, retains the key levers and restricts the options available to the management of a public firm. When it is time to plunge into international markets or else to withdraw from contention, senior managers in a public firm are likely to depend for sustenance instead upon a protected domestic market base. This is a realistic assessment of how difficult it is to integrate politicians into the firm's planning and to make tough decisions in the inevitable "fishbowl" of public life.

By contrast, in entrepreneurial industries, successful business leaders act with a high degree of independence from their constituents. Major firms attain independence for top management by diversifying their product markets and their sources of finance. The managers signal their commitment to the long-term interests of the shareholders by having a large equity stake in the firm and through incentive compensation schemes in the particular project. Their self-interest is also bound to the firm, since they have usually risen through the ranks.

Since competition in entrepreneurial industries takes the form of swift rivalry for dominance, victory will go to the successful strategist. Having a good "mousetrap" helps, but it is not sufficient to assure success. Strategy for success in rivalry among giants from which only a handful will survive, requires managers with imagination, verve, prowess, and staying power. The successful strategist is a firm that initiates change, scans for opportunities, and is experimental and flexible. A firm that is a reactor incapable of articulating a viable long-term strategy or of adopting the appropriate organizational culture and that is overzealously committed to counterproductive strategies is unlikely to be in the industry when the "shake-out" is complete.

In the nuclear reactor business, Westinghouse has from the outset been the "mover and the shaker." It "loss-leadered" nuclear power stations on a turnkey, fixed-price basis; it guaranteed the price of uranium under long-term sales contracts; and it licensed its technology and entered joint ventures in France, Japan, and elsewhere. General Electric pursued similar strategies.

In its nuclear reactor program, Canada has displayed no similar capacity for marketing entrepreneurship. It focused on Ontario and did not diversify its market options. Though that was a natural step for a mission-oriented and risk avoiding firm, a commercial "venturer," with the knowledge that long-run survival is unlikely if based solely on the domestic market and aiming at the world market, would have acted differently. When it realized late in the day that it would lose credibility at home and abroad if it failed to sell reactors outside Canada, AECL concentrated its marketing efforts on countries with weak economies. Third World markets have predictably become a dumping ground in which manufacturers with protected home markets sell at concessionary prices when they have excess capacity or when they are seeking scale through marginal sales abroad.

Because AECL was convinced that industrial countries would protect their home markets, it stayed out of the U.S. and German markets. Those large markets for reactors should have been entered because in both countries there were opportunities to sell to privately-owned utilities. More vigorous development of the CANDU during the late 1960s might have led to success for Canada in the United Kingdom or France, where prestige tended to exclude foreign technologies. Now France has become a dominant force in the light-water reactor technology it acquired from the United States, and the United Kingdom is also moving in the U.S. direction.

The most damaging marketing failure during the critical years between 1964 and 1974 was the cavalier attitude to heavy-water development and pricing. Though fears about the supply and cost of heavy water was the Achilles heel of the CANDU program, no dramatic steps seem ever to have been taken to dispel customer concerns about its cost and availability. The U.K. rejection of the CANDU in the early 1970s is alleged to have been due to the cost of heavy water and the risk of producing it in highly populated areas (see Milne and Pearce 1983). In the mid-1960s, when customers were worried that the CANDU might leak heavy water, AECL should have guaranteed supplies at its own expense. Later, when AECL was able to establish that CANDU is leakproof, it should have guaranteed firm concessionary prices for heavy water.

At this moment in time, quite substantial sums are needed if CANDU is to survive until the nuclear reactor market recovers perhaps after 1995. Perhaps the industry should be allowed to struggle along, staying busy refurbishing Pickering and working on the odd foreign sale like the one to Romania and the possible sale to Turkey. The private sector is reported to have only $240 million in specialized capital facilities committed to the CANDU, but the work force comprises highly skilled workers who would certainly find alternative employment. Much of the dedicated capital would likely find alternative uses. But if the industry does not receive a major financial infusion to carry it into the next century, it is unlikely to survive. A dormant industry cannot be brought back to life unless all CANDU's rivals also top their research and development work. There is little prospect of that happening, and new reactor concepts are being demonstrated, while efforts are being made to improve old ones.

It is by no means certain that the market for nuclear power will revive, though all indications are that a modest revival is due after 1995. Even if there is a revival, however, there is no guarantee that CANDU will be able to compete with its rivals, even for sales in the Canadian market. If CANDU is to be allowed to wither and AECL to join the class of firms described in the venture capital industry as "the living dead," consideration should be given to a merger of all or part of AECL with Ontario Hydro. Alternatively, if the government should choose to invest heavily in a new effort to prepare for the next round of reactor orders, then some form of privatization of all or part of AECL should be seriously considered. Another option is for Canada to find a partner for AECL from among a group of foreign nuclear firms – private or public. A joint venture could reduce the research and development costs of a new generation of reactors and present a larger captive market in which to sell.

This study does not provide a sufficient basis for deciding on either AECL's or CANDU's future. What is needed is a far broader effort to forecast alternative futures for nuclear power than is available here. What we have concluded from this case study of AECL is that a Crown corporation is not an attractive instrument for fostering the dynamic development of comparative advantage when commercialization must take place in competition with both private and public firms sponsored by other governments worldwide. Greater consideration should be given to channelling government support for commercializing new technologies to private enterprises.

Notes

CHAPTER 4

1 In a private communication, Professor D. A. Meneley, disputes this judgement. He advises that any attempt to sell CANDU in the United States during the 1960s would have run afoul of the U.S. licensing authorities. Concepts not favoured by the U.S. Navy, Westinghouse, and General Electric were eliminated. Possibly so, but it remains true that I found no evidence of an effort during the 1960s to overcome U.S. parochialism through government pressure or to subsidize sales in European markets like Germany, or to seek partners in order to internationalize the development of CANDU.

CHAPTER 5

1 Don McFetridge points out that I am less than clear about an appropriate real rate of discount. Throughout the paper I use a real rate of 7.5 per cent, which is the social rate of discount used also by the Department of Energy, Mines and Resources (1981*b*; 1982). The confusion over rates is understandable because the OECD study uses a 5 and 10 per cent rate. Ontario Hydro studies usually forecast nominal interest rates and prices, from which the real rate is inferred. The real rate used by one Ontario Hydro study was as low as 2 per cent during the same period. France in the 1960s used a 9 per cent real rate as a hurdle rate when evaluating investments in electricity-generating capacity. Given this range of rates that have been used to evaluate the cost effectiveness there is no wonder that confusion might prevail about the true cost of nuclear power.

CHAPTER 6

1 It is true, as one reader of this study has pointed out, that the subsidy to Ontario Hydro also includes relief from legal liability for damages caused by a nuclear accident. By statute, there is a maximum amount a utility and a reactor manufacturer could be forced to pay in the event of an accident (see Nuclear Liability Act, June 1970). This subsidy is certainly substantial, but it is difficult to quantify. In this study the subsidy is overlooked because it is relevant only when comparing nuclear power costs with coal-generated power costs. Since in Ontario light-water reactors are the best alternative to the CANDU, the insurance subsidy provided by the Canadian government would apply in both cases and would not affect a comparative analysis unless one system is inherently safer than the other, a position supporters of the CANDU would dispute. Nevertheless, it is true that any economic advantage that nuclear power in any form may have relative to coal-fired power stations should be reduced by an estimate of the value of the insurance provided free of charge by Canadian taxpayers and unwittingly by residents in the vicinity of a nuclear power station.

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Bibliography

"A breeder reactor that may melt away." 1982. *Business Week* (September 6):30-31.

"Administration articulates a new nuclear strategy." 1984. *Public Utilities Fortnightly* (June 7):39-40.

ADDINALL, E. and H. ELLINGTON. 1982. *Nuclear Power in Perspective*. London: Kogan Page Publishers.

AHEARNE, John F. 1984. "Prospects for the U.S. nuclear reactor industry." *Annual Review of Energy* 8:355-84.

AIKEN, A. M. 1970. "Marketing nuclear power plants." Canadian Nuclear Association Annual Conference 70-CNA-647.

ALBERTA WHITE PAPER. 1984. Proposals for an *Industrial and Science Strategy for Albertans, 1985-1990* (July).

ALCHIAN, A. A. and H. DEMSETZ. 1972. "Production, information costs and economic organizations." *American Economic Review*, Vol. LXIII, pp. 777-95.

ALLISON, David. 1969. *The R&D Game*. Cambridge, Mass.: MIT Press.

ALLISON, Graham T. 1971. *Essence of Decision, Explaining the Cuban Missile Crisis*. Boston, Mass.: Little, Brown and Company.

ALWARD, Peter T. 1981. *CANDU: Sales and Safeguards*. Ottawa: Library of Parliament (May 26).

"American fast breeder faces a sterile future." 1982. *New Scientist* (September 30):895.

ANDERSON, A. 1984. "Lawsuit dismissed" and "Operation of power plants." *Nature* 31, No. 5976 (August 2):357.

ANDREWS, Robert. 1982. "Power failure: Why we can't sell nuclear." *Canadian Business* 55, No. 11 (November):133-36.

"Are utilities obsolete? A troubled system faces radical change." 1984. *Business Week* (May 21):116-19.

ASHLEY, C. A. and R.G.H. SMAILS. 1965. *Canadian Crown Corporations: Some Aspects of Their Administration and Control*. Toronto: Macmillan.

ATOMIC ENERGY OF CANADA LIMITED. 1968. Submission to the Senate of Canada Special Committee on Science Policy, October 1968. In *Proceedings of the Special Committee on Science Policy* (October 30-31, 1968):647-1047, including a brief by Eldorado Nuclear, p. 893.

______. 1983. Management and Control Practices. Policy #10302 (November).

______. 1984. Executive Resources Plan. Policy #20102 (May).

"Attention focusses on Pickering rupture." 1983. *Nuclear Engineering International* (October):9-10.

BACHAND, Raymond C. 1981. "Boards of Directors in Canadian government enterprises: An exploratory research." Ph.D. Thesis, Graduate School of Business Administration, Harvard University. Ann Arbor, Michigan: University Microfilms International, 1984.

BAINBRIDGE, G. R.; D. PAHLEY; D.T.H. ROWLANDS; and C. V. WAGSTAFF. 1968. "Factors affecting costs of nuclear power stations." *International Comparison of Nuclear Power Costs*. Vienna: International Atomic Energy Agency, pp. 139-54.

BALDWIN, John R. 1975. *The Regulatory Agency and the Public Corporation*. Cambridge, Mass.: Ballinger Publishing.

______. 1984. "Regulation versus public enterprise as an instrument of government policy: A transactions failure analysis." Queen's University, Kingston, Ont. Mimeographed.

BANERJEE, S. and L. WAVERMAN. 1978. "Life cycle costs of coal and nuclear generating stations." Report submitted to the Royal Commission on Electric Power Planning. Toronto (July).

BARKENBUS, Jack N. 1983. "Is self-regulation possible?" *Journal of Policy Analysis and Management* 2(Summer): 576-88.

BEIGIE, Carl E. and Judith MAXWELL. 1977. "Quebec's vulnerability in energy." C. D. Howe Research Institute, Accent Quebec, Montreal.

BERLE, A. A. Jr. and Gardiner C. MEANS. 1982. *Modern Corporations and Private Property*. Reprint of 1933 edition, xiii, 396 pages. Business Enterprises Reprint Services.

BORINS, S. F. and B. BOOTHMAN. 1984. "Crown corporations and economic efficiency." Mimeographed. Forthcoming in background papers for The Royal Commission on the Economic Union and Canada's Economic Development, Vol. 3.

BOS, Dieter. 1981. Lecture Notes in Economics and Mathematical Systems in *Economic Theory of Public Enterprise*. Berlin, Heidelberg and New York.

BRADFORD, David L. and Allan R. COHEN. 1984. *Managing for Excellence*. New York: John Wiley.

BRADY, Rosemary. 1984. "The sorcerer's apprentice." *Forbes* (September 24):106,110.

BRODY, M. 1981. "Nuclear fizzle? Costs, risks of atomic power may escalate past point of no return." *Barron's* 61 (August 24):4-5.

BROOKES, Leonard G. and Moma MOTAMEN (eds.). 1984. *The Economics of Nuclear Energy*. London/New York: Chapman and Hall.

BRUCE, Geoffrey F. 1975. "Salvation or Armageddon? The dilemma of nuclear power." *International Perspectives* (May/June):31-36.

BUGLER, Jeremy. 1976. "Windscale's fuel for controversy." *New Statesman* 92 (November 26):740-41.

______. 1977*a*. "Nuclear politics in France." *New Statesman* (August 26):266-67.

______. 1977*b*. "Nuclear civil war." *New Statesman* 94 (November 4):603-604.

BUPP, I. C. 1980. "The French nuclear harvest: Abundant energy or bitter harvest?"*Technology Review* (November/ December):30-9.

______. 1981. "The actual growth and probable future of the worldwide nuclear industry." *International Organization* 35, No. 1 (Winter):54-76.

BUPP, I. C. and Jean-Claude DERIAN. 1978. *Light Water: How the Nuclear Dream Dissolved*. New York: Basic Books.

BURN, D. 1978. *Nuclear Power and the Energy Crisis: Politics and the Atomic Industry*. London: Macmillan.

BURN, Duncan and Barbara EPSTEIN. 1972. *Realities of Free Trade: Two Industry Studies*. Toronto: University of Toronto Press and George Allen and Unwin Ltd.

BURNS, Janet Marie Frances. 1980. "A public choice theory perspective of the Canadian nuclear industry." Thesis, University of Carleton, Ottawa.

BURNS, Tom and G. M. STALKER. 1971. *The Management of Innovation*. 3rd ed. London: Tavistock Publications.

BUZZELL, R. D.; B. T. GALE; and R.G.M. SULTAN. 1975. "Market share – A key to profitability." *Harvard Business Review* (January/February):97-106

CAMILLERI, Joseph A. 1982. *The Political Economy of Nuclear Power: Comparative Study*. London: Wheatsheaf Books.

______. 1984. *The State and Nuclear Power: A Comparative and International Perspective*. Seattle: University Washington Press.

CAMPBELL, H. F. 1982. "A benefit/cost rule for an additional public project in Canada." Ph.D. Dissertation, Queen's University, Kingston, Ontario.

CANADA. DEPARTMENT OF ENERGY, MINES AND RESOURCES. 1973. *An Energy Policy for Canada – Phase 1: Volume I – Analysis* and *Volume II – Appendices*. Ottawa: Information Canada.

______. 1978. *Energy Strategy for Canada: Policies for Self-Reliance*. Ottawa: Supply and Services Canada.

______. 1981*a*. *Energy Update*. April 1981. Report ER81-4E. Ottawa: EMR.

______. 1981*b*. *Nuclear Policy Review: Background Papers*. Report ER81-2E. Ottawa: Supply and Services Canada.

______. 1982. *Nuclear Industry Review: Problems and Prospects, 1981-2000*. Ottawa: Supply and Services Canada.

CANADA. DEPARTMENT OF FINANCE. 1984. *A New Direction for Canada*. Ottawa: Dept. of Finance.

CANADA. DEPARTMENT OF INDUSTRY, TRADE AND COMMERCE. 1978. Report by the *Task Force on CANDU Export Marketing (Douglas Report)*. Ottawa: IT&C.

"Canada looks for exports." 1983. *Nuclear Engineering International* (August):4.

CANADA. ROYAL COMMISSION ON THE ECONOMIC UNION AND DEVELOPMENT PROSPECTS FOR CANADA. 1985. *Report*. Vols. 1, 2, and 3. Ottawa: Supply and Services Canada.

CANADA. TASK FORCE ON FEDERAL POLICIES AND PROGRAMS FOR TECHNOLOGY DEVELOPMENT. 1984. *Report* of the Chairman, Douglas Wright, to Edward C. Lumley, Minister of State. Ottawa: Supply and Services Canada.

"Canada's nuclear future stands on exports." 1981. *Nuclear Engineering International* 26 (July):11-12.

CANADIAN NUCLEAR ASSOCIATION. 1981. *Nuclear Power in Canada: Questions and Answers*. 2nd ed. Toronto: CNA Publishers.

CARMICHAEL, Jeffrey. 1981. "The effects of mission-oriented public R&D spending on private industry." *The Journal of Finance* 36 (June):617-27.

CASTERTON, James A. 1980. "The international dimensions of the Canadian nuclear industry." M.A. Thesis, Norman Paterson School of International Affairs, Carleton University, Ottawa.

CAVANAUGH, H. A. 1984. "How do private and public CEO salaries compare?" *Electrical World* (August):27-29.

CAVES, Douglas and Laurits R. CHRISTENSEN. 1980. "The relative efficiency of public and private firms in a competitive environment: The case of Canadian railroads." *Journal of Political Economy* 88(5):953-76.

CHASE, Dennis J. 1975. "Clouding the nuclear reactor debate: A commentary." *Bulletin of the Atomic Scientists* (February):39-40.

CHOW, Brian G. 1977. "The economic issues of the Fast Breeder Reactor Program." *Science* (February 11):551-56.

CICHETTI, J. and Wm. J. GILLEN. 1977. Ontario Energy Board. Exhibit #11. Ontario Hydro evidence presented on behalf of the Attorney General of Canada. Toronto (May 16).

CLARKSON, Ken and Donald L. MARIN (series editors). 1980. *The Economics of Nonproprietary Organizations*. Supplement 1, in Research in Law and Economics. Greenwich, Conn.: JAI Press.

COCHRAN, T. B. 1974. *The Liquid Metal Fast Breeder Reactor: An Environmental and Economic Critique*. Resources for the Future. Washington D.C.: U.S. Government Printing Office.

COLLINGRIDGE, D. 1984*a*. "Lessons of nuclear power: French 'success' and the breeder." *Energy Policy* (June):189-200.

______. 1984*b*. "Lessons of nuclear power: U.S. and U.K. history." *Energy Policy* (March):46-67.

COOK, Franklin H. 1969. "Public ownership: United Kingdom vs. United States." *Public Utilities Fortnightly* 84 (December 18):26-34.

COOK, James. 1985. "Nuclear follies." *Forbes* 135 (February 11):82-96.

COTTRELL, Sir Alan. 1981. *How Safe is Nuclear Energy?* London: Heinemann Educational Books Ltd.

CREW, M. A. 1983. *Regulatory Reform and Public Utilities*. Lexington, Mass.: Lexington Books.

DAY, M. C. 1975. "Nuclear energy: A second round of questions." *Bulletin of the Atomic Scientist* (December):52-59.

DEALESSI, Louis. 1969. "Implications of property rights for government investment choices." *American Economic Review* 59 (1969):13-24.

______. 1974*a*. "An economic analysis of government ownership and regulation: Theory and the evidence from the electric power industry." *Public Choice* 19 (Fall):1-42.

______. 1974*b*. "Managerial tenure under private and government ownership in the electric power industry." *Journal of Political Economy* 82 (May/June):645-53.

______. 1975. "Some effects of ownership on wholesale prices of electric power." *Economic Inquiry* 13 (December):526-38.

DELEON, Peter. A. 1976. *Cross Comparison of Nuclear Development Strategies*. Santa Monica, Calif.: Rand Corporation, p. 20.

______. 1980. *Development and Diffusion of the Nuclear Power Reactor: A Comparative Analysis*. Cambridge, Mass.: Ballinger Publishing.

DENTON, H. R. 1983. "Nuclear power, epilogue or prologue?" *Energy Journal* 4 (January):139-41.

"Developing reactor designs for the 1990's." 1983. *Nuclear Engineering International* (June):46-47.

DICKSON, David. 1982. "Europe's fast breeders move to a slow track." *Science* 218 (December 10):1094-97.

______. 1984. "France invites U.S. participation on breeders." *Science* 224 (May 18):697.

DICKSON, Douglas (ed.). 1983. *Managing Effectively in the Global Marketplace*. New York: John Wiley.

DOERN, Bruce G. 1976. *The Atomic Energy Control Board*. Study for the Law Reform Commission. Ottawa: Supply and Services Canada, Chapters 2 and 3.

______. 1980. *Government Intervention in the Canadian Nuclear Industry*. Canadian Atomic Energy Policy. Montreal: IRPP.

______. 1984. "Atomic Energy of Canada Ltd.: Selected performance issues." Paper presented to the Symposium on Crown Corporations, Carleton University, Ottawa (June 1).

DOERN, Bruce G. and Robert W. MORRISON (eds.). 1980. *Canadian Nuclear Policies.* Proceedings of a November 1978 Conference. Montreal: IRPP.

DOERN, Bruce G. and Gordon SIMS. 1980. "Atomic Energy of Canada Ltd." Chapter 2 of "Spending tax dollars: Federal expenditures, 1980-81," edited by Bruce G. Doern. School of Public Administration, Carleton University, Ottawa, pp. 49-73.

DONALDSON, Gordon and Jay W. LORSCH. 1983. *Decision Making at the Top.* New York: Basic Books Inc.

DOUB, W. O. and J. M. DUKERT. 1975. "Making nuclear energy safe and secure." *Foreign Affairs* 53 (July):756-62.

DOUGLAS, Carole. 1984. "The economics of contamination." *The Atlantic* (October):29-36.

"Downsizing nuclear plants." 1980. *Business Week* 2662 (November 10):114.

DUDERSTADT, James J. and Chihiro KIKUCHI. 1979. *Nuclear Power Technology on Trial.* Ann Arbor: University of Michigan Press.

DUFFY, Gloria C. and Gordon ADAMS. 1978. "Power politics: The nuclear industry and nuclear exports." *Council on Economic Priorities.* Washington, D.C.: U.S. Government Printing Office.

DUFFY, John. 1980. "Can the slowpoke do what CANDU can't?" *Canadian Business* 53, No. 8 (August):27-32.

EDWARDS, Gordon [Chairman of Canadian Coalition for Nuclear Responsibility]. 1982. "Cost disadvantages of expanding the nuclear power industry." *The Canadian Business Review* 8, No. 1 (Spring).

EFFORD, Ian E. and Barbara M. SMITH (eds.). 1971. *Energy and the Environment.* H. R. MacMillan lectures. Institute of Resource Ecology, University of British Columbia, Vancouver.

EGAN, J. R. 1981. "Nuclear power: The future of small reactors." *Current* 241 (March/April):31-35.

EGGLESTON, Wilfred. 1965. *Canada's Nuclear Story.* Toronto: Clark Irwin.

ELLIS, Randall P. and Martin B. ZIMMERMAN. 1983. "What happened to nuclear power: A discrete choice model of technology adoption." *The Review of Economics and Statistics* 65 (May):234-42.

EVANS, Nigel and Chris HOPE. 1983. *Nuclear Power: Futures, Costs and Benefits.* Cambridge, Mass.: Cambridge University Press.

FAGNANI, Jeanne and Jean-Paul MOATTI. 1984. "The politics of French nuclear development." *Journal of Policy Analysis and Management* 3 (Winter):264-75.

FISCHHOFF, Baruch. 1983. "'Acceptable risk': The case of nuclear power." *Policy Analysis and Management* 2 (Summer):559-75.

FLAVIN, Christopher. 1984*a*. *Electricity's Future: The Shift to Efficiency and Small-Scale Power.* Worldwatch Paper 61. Worldwatch Institute, Washington, D.C.

______. 1984*b*. "Reassessing the economics of nuclear power." *Interciencia* 9 (July/August):192-205.

FLEMING, James. 1984. "CANDU's Turkish connection." *Macleans* (October):36.

FONG, J.V.C.; J. Basu ROY; G. N. MEEHAND; and G. F. McINTYRE. 1982. *Cost Comparison of CANDU Nuclear and Coal-Fuelled Generating Stations.* Report #620SP. Toronto: Ontario Hydro.

FORD FOUNDATION. 1974. *Exploring Energy Choices.* Energy Policy Project. Washington, D.C.: U.S. Government Printing Office.

______. 1979. *Energy: The Next Twenty Years.* Cambridge, Mass.: Ballinger Publishing.

FORD, Daniel. 1982. *Cult of the Atom.* New York: Simon and Schuster.

FORD, Daniel et al. 1973. *The Nuclear Fuel Cycle: A Survey of the Public Health, Environment and National Security Effects of Nuclear Power.* Union of Concerned Scientists. Cambridge, Mass.

FORD-MITRE REPORT. 1977. *Nuclear Power: Issues and Choices.* Nuclear Energy Policy Study Group. Cambridge, Mass.: Ballinger Publishing, Chapters 8 and 9.

FOREMAN-PECK, James and Michael WATERSON. 1985. "The comparative efficiency of public and private enterprise in Britain: Electricity generation between the wars." *Economic Journal* 95(March):83-95.

FORTUNE, R. F. 1978. "Canadian experience in the international nuclear power market." International Comparison of Nuclear Costs. Proceedings of International Atomic Energy Agency Symposium, London, England (October 1976). Vienna: IAEA, pp. 155-71.

"Framatome 600-MWE nuclear island for export markets." 1981. *Nuclear Engineering International* 26 (Spring):33-39.

"France: Atomic amour." 1981. *The Economist* 280, No. 7202 (September 21):50.

"France: A two-pronged spur for nuclear reactor." 1981. *Business Week* (February 23):50-52.

FREEMAN, S. David. 1983. "Reinventing the nuclear wheel." *Across the Board* (October):30-34.

"Future dubious for CANDU exports." 1979. *Nuclear Engineering International* (September):5.

Generation Nuclear. 1977. Submission to the Royal Commission on Electric Power Plannings, Final Hearings (June).

"Germany's turning point for nuclear energy?" 1981. *Business Week* (February 23):50-52.

"Getting rid of it." 1982. *The Economist* 283, No. 7239 (May 29):93-94.

GOLAY, Michael W. 1984. "Rx for nuclear power: An agenda for improving present-day reactors." *Technology Review* 87 (February/March):49-51.

GOLDSCHMIDT, B. 1982. *The Atomic Complex: A Worldwide Political History of Nuclear Energy*. Illinois: American Nuclear Society, 1982.

GORDON, Marsha. 1981. *Government in Business*. Montreal: C. D. Howe Institute, Chapter 6, pp. 169-79 and 186-91.

GOULD, Jay M. 1984. "The future of nuclear power." *Monthly Review* 35 (February):7-14.

GRANLI, Lief et al. *Nuclear Power and Safety*. New York: Columbia University Press.

GREEN, R. E. and R. M. WILLIAMS. *Nuclear Energy – One Road to Self-Sufficiency*. Atomic Energy of Canada Report AECL-6963. Ottawa: AECL.

GRILICHES, Zvi. 1979. "Issues in assessing the contribution of research and development to productivity growth." *Bell Journal of Economics* 10(1):92-116.

GUMMER, W. K. 1982. *Regulation of the Canadian Nuclear Industry*. Ottawa: Atomic Energy Control Board.

HARRIS, Richard G. 1984. "Trade, industrial policy and international competition." Report prepared for the Royal Commission on the Economic Union and Development Prospects for Canada (February).

"Heavy water: Special issue." 1966. *Nuclear Engineering International* (June):11, 121.

HELLMAN, Richard and Caroline J. C. HELLMAN. 1983. *The Competitive Economics of Nuclear and Coal Power*. Lexington, Mass.: Lexington Books.

HILL, Phillip G. 1977. *Power Generation: Resources, Hazards, Technology, and Costs*. Cambridge, Mass.: MIT Press.

HINTON, Christopher. 1955. "The Graphite Moderated Gas Cooled Pile." *Power Reactors*. Vol. 3. New York: United Nations.

HIRSHHORN, Ronald. 1984. "Government enterprise and organizational efficiency." Economic Council of Canada, Ottawa. Mimeographed.

HOME OIL COMPANY LIMITED. 1969. "Energy demand forecast: Canada (Ontario and Quebec), 1970 – 1985." Prepared by Home Oil Company Limited with the co-operation of Purvin and Gertz Inc. of Dallas, Texas.

HOOKER, C. A.; R. MACDONALD; R. VAN HULST; and P. VICTOR. 1981. *Energy and the Quality of Life: Understanding Energy Policy*. Toronto: University of Toronto Press.

HOYLE, Fred. 1977. *Energy or Extinction? The Case for Nuclear Energy*. London: Heinemann Educational Books Ltd.

HUG, M. 1981. "How the French program is benefiting from standardization." *Nuclear Engineering International* 26(July):29-32.

HUNT, Constance D. 1977. "Canadian policy and the export of nuclear energy." *University of Toronto Law Journal* 17 (1977):69-104.

HYDRO-QUÉBEC. 1980. *A Strategy for the 80's*. Montreal: Hydro-Québec (December 16).

JACKSON, H. A.; L. W. WOODHEAD; and G. R. FANJOY. 1983. "Economics of Candu-PHW." Ontario Hydro Report NGD-10. Toronto: Ontario Hydro.

JAUCH, Lawrence R. A. 1983. "A descriptive inventory of some cutting edge research on strategic management." Souther Illinois University-Carbondale. Mimeographed.

JENKINS, Glenn P. 1980. "Public utility finance and economic waste." Harvard Institute for International Development. Harvard University. Unpublished paper.

JENNEKENS, Jon H. F. 1979. "Nuclear energy in Canada: In search of the definitive inquiry." Presentation to the Society of AECL Professional Engineers, Whiteshell Nuclear Research Establishment, Pinawa, Manitoba (October 4, 1979). Ottawa: Atomic Energy Control Board.

JENSEN, Michael C. and Richard S. RUBACK. 1983. "The market for corporate control: The scientific evidence." *Journal of Financial Economics* (April).

JENSEN, Michael C. and Clifford W. SMITH, Jr. (eds.). 1984. *The Modern Theory of Corporate Finance*. New York: McGraw-Hill.

JENSEN, Michael C. and Jerold L. ZIMMERMAN (eds.). 1985. "Symposium on management compensation and the managerial labor market in honor of William H. Meckling." *Journal of Accounting and Economics* 7 (April).

JOSKOW, Paul L. 1976. "The international nuclear industry today." *Foreign Affairs* 54, No. 4 (1975-76):788-803.

______. 1977. "Commercial impossibility: The uranium market and the Westinghouse case." *Journal of Legal Studies* 6 (January):119-76.

JOSKOW, Paul L. and G. ROZANSKI. 1979. "The effects of learning by doing on nuclear plant operating reliability." *Review of Economics and Statistics* 61, No. 2 (May):161-68.

JOSKOW, Paul L. and Richard SCHMALENSEE. 1983. *Markets for Power: An Analysis of Electric Utility Deregulation*. Cambridge, Mass.: MIT Press.

KAKU, Michio and Jennifer TRAINER. 1982. *Nuclear Power: Both Sides*. New York: W. W. Norton & Co.

KAMIEN, Morton I. and Nancy L. SCHWARTZ. 1982. *Market Structure and Innovation*. Cambridge, Mass.: Cambridge University Press.

KAY, Neil M. 1982. *The Evolving Firm*. New York: St. Martin's Press.

KECK, Otto. 1980. "Government policy and technical choice in the West German reactor programme." *Research Policy* 9:335.

KEELEY, James F. 1980. "Canadian nuclear export policy and the problems of proliferation." *Canadian Public Policy* 6 (Autumn):614-27.

KIKUNSKI, J. M.; W. D. KAY; and D. S. METLAY. 1982. "Citizen knowledge and choices on the complex issue of nuclear energy." *American Journal of Political Science* 76:615-42.

KNELMAN, F. H. 1976. *Nuclear Energy: The Unforgiving Technology*. Edmonton: Hurtig Publications.

KNOX, Richard. 1981. "CANDU and power costs compared in Canada." *Nuclear Engineering International* 26 (August):25-26.

KOMONOFF, Charles. 1977. *Power Plant Cost Escalation: Nuclear and Coal Capital Costs, Regulation and Economics*. New York: Komonoff Energy Association.

KREUGER, Anne O. 1974. "The political economy of the rent-seeking society." *American Economic Review* 64:291-303.

LANGFORD, W. J. and H. K. RAE. 1980. "Some highlights of R&D at AECL." Ottawa: AECL Report, AECL-6954.

LANOUETTE, William J. 1980. "The 'CANDU' reactor from Canada – Can it do the job down here?" *National Journal* 12(June 28):1061-63.

LEBLOND, D. 1980. "Taking the lead in nuclear power." *Petroleum Economist* 47 (February):52-54.

______. 1984. "European energy report." *Petroleum Economist* 51 (February):62-63.

LECRAW, Donald J. 1984*a*. "Industry decline and growth: Industrial policy and corporate strategy." Report prepared for the Royal Commission on the Economic Union and Development Prospects for Canada, February 1984 (revised May 1984).

______. 1984*b*. "Industrial policy in the United States: A survey." Report prepared for the Royal Commission on the Economic Union and Development Prospects for Canada, February 1984 (revised June 1984).

LEGAULT, Albert. 1976. "Nuclear policy should be more open and less ambiguous." *International Perspectives* (January/February):8-13.

______. 1978. "Arrangements and techniques to safeguard nuclear material." *International Perspectives* (September/October):24-27.

LENY, J. C. 1979. "Single suppliers chosen for efficiency." *Nuclear Engineering International* (March):54-62.

LEONARD AND PARTNERS. 1978. "Economic impact of nuclear energy industry in Canada. Executive summary." Canadian Nuclear Association, Ottawa.

LESTER, Richard. 1983. "Japan's lead in nuclear power." *Wall Street Journal* (November 16):30.

______. 1984. "Rx for nuclear power: The need for nuclear innovation." *Technology Review* 87 (February/March):45-48.

LICHTENBERG, Frank R. 1984. "The relationship between federal contract R&D and company R&D." *American Economic Review* 74 (May):73-78.

LIDSKY, Lawrence M. 1984. "Rx for nuclear power: The reactor of the future?" *Technology Review* 87 (February/March):52-56

LILIENTHAL, David E. 1980. *Atomic Energy: A New Start*. New York: Harper and Row.

LONROTH, Mans and William WALKER. 1979. "The viability of the civilian nuclear industry." International Consultative Group on Nuclear Energy, and sponsored jointly by the Rockefeller Foundation and the Royal Institute on International Affairs. New York and London, respectively.

LORTIE, Pierre and R. SCHWEITZER. 1981. *A Strategy for the Development and Strengthening of the Canadian Nuclear Industry*. Final Report. Montreal: Secor Inc.

LUCAS, Alastair R. and Trevor BELL. 1977. *The National Energy Board: Policy, Procedure and Practice*. Report prepared for the Law Reform Commission of Canada. Ottawa: Supply and Services Canada.

LUCE, Charles F. 1983. "Where is the electric utility industry headed in the 1980s?" *Public Utilities Fortnightly* (June 23):15-19.

LYNEIS, James M. and Dominic M. GERAGHTY. 1984. "Electric utility strategies for the eighties: Taking advantage of a 'window of opportunity.'" *Public Utilities Fortnightly* (May 24):17-23.

MACKENZIE, James J. 1984. "Rx for nuclear power: Finessing the risks of nuclear power." *Technology Review* 87 (February/March):34-44.

MACNABB, G. M. 1975. *Nuclear and Uranium Policies*. Proceedings of Canadian Nuclear Association Annual Conference, p. 20.

MALATESTA, Paul H. 1983. "The wealth effect of merger activity and the objective functions of merging firms." *Journal of Financial Economics*.

MANSFIELD, Edwin and Lorne SWITZER. 1984. "Effects of federal support on company financed R&D: The case of energy." *Journal of Management Science*.

MARCUS, Gail M. 1983. "Japan, Inc. and Nuclear Power." *Public Utilities Fortnightly* 5, No. 112 (September 29):40-42.

"Maritime lays plans for Point Lepreau 2." 1983. *Nuclear Engineering International* (November):12.

MARSCHAK, Jacob and Sam H. SCHURR (eds.). 1950. *Economic Aspects of Atomic Power*. Cowles Commission for Research in Economics. Princeton: Princeton University Press.

MARSHALL, Elliot. 1982. "The perils of Clinch River." *Science* 218 (October):137-38.

______. 1984. "The secret recipe of GE's reactor safety study." *Science* 225 (July):294.

MARTENSSON, M. 1968. "A statistical analysis of the construction costs of a nuclear power plant." International Comparison of Nuclear Power Costs. Proceedings of a symposium, London (October 1967). Vienna: International Atomic Energy Agency, pp. 125-28.

MARTINO, Joseph P. 1983. *Technological Forecasting for Decision Making*. 2nd ed. Amsterdam, New York, Oxford: North-Holland.

MASELLA, I. M. 1984. "Rate moderation plans – cushioning rate shock." *Public Utilities Fortnightly* 113 (February):52-56.

MATHER, J. P. 1983. "World nuclear power reactor performance." Ontario Hydro Report NGD-12. Toronto: Ontario Hydro.

MATSUDA, Yasushi. 1984. "Nuclear power in Japan: Present and future." *Journal of Japanese Trade and Industry* 6 (November/December):12-26.

MCFETRIDGE, D. G. 1984. Some Thoughts on Crown Corporations: A Discussion of Issues Raised at the Symposium on Crown Corporation Performance. Mimeographed.

______. 1985. "Commercial efficiency and political efficiency: A comparison of government, mixed and private enterprises." In *Canadian Industrial Policy in Action*, ed. McFetridge. A study commissioned for the Royal Commission on the Economic Union and Development Prospects for Canada. Toronto: University of Toronto Press.

MCINTYRE, Hugh. 1979. "Conflicting estimates create uncertainties for CANDU." *Energy International* 16 (May):28-30.

MEYER, M. B. 1984. "Nuclear power plant cost underestimation: Mechanisms and corrections." *Public Utilities Fortnightly* 113 (February):28-31.

MILES, Raymond E. and Charles C. SNOW. 1978. *Organizational Strategy, Structure, and Process.* New York: McGraw-Hill.

MILLER, Sarah A. 1978. "A nuclear difference: At stake is Europe's energy supply and/or the future of mankind." *European Community* (May/June):30-33.

MILLS, Mark P. and Roger STARR. 1983. "France declares energy independence." *Across the Board* 20, No. 3 (March). New York: The Conference Board Inc.

MILNE, Roger and Fred PEARCE. 1983. "Why Britain said 'No CANDU.'" *New Scientist* 98 (January):614.

MONTGOMERY, David W. and James P. QUIRK. 1976. "Cost escalation in nuclear power." National Science Foundation, Energy Research and Development Administration, Environmental Quality Laboratory. Pasadena, Calif.: California Institute of Technology.

MOSS, Norman. 1981. *The Politics of Uranium.* New York: Universe Books.

MURRAY, Alex J. (ed.). 1975. "American energy in perspective." Proceedings of the 16th annual University of Windsor seminar on Canadian-American relations (November 14-15, 1974). Windsor: University of Windsor.

NASTICH, Milan. 1981. "Cost advantages of nuclear energy in Ontario." *The Canadian Business Review* 8 (Winter):33-36.

NELLIS, R. E. 1983. "Allocating nuclear power plant costs over time." *Public Utilities Fortnightly* 112 (September):22-27.

NELSON, Richard R.; Merton J. PECK; and Edward D. KALACHEK. 1967. *Technology Economic Growth and Public Policy.* A Rand Corporation and Brookings Institution Study. Washington D.C.: The Brookings Institution.

NELSON, Richard R. and Sidney G. WINTER. 1982. *An Evolutionary Theory of Economic Change.* Cambridge, Mass.: The Belknap Press of Harvard University Press.

NOBLE, John J. 1978. "Canada's continuing search for acceptable nuclear safeguards." *International Perspectives* (July/August):42-48.

NORDHAUS, William D. 1977. "What is the value of advanced nuclear power?" Discussion Paper 449. Cowles Foundation for Research in Economics at Yale University, New Haven, Connecticut.

"Nuclear reactors: French model." 1980. *The Economist* 277 (October 18):116.

"Nuclear power: Exit problems." 1984. *The Economist* (July 28):29.

"Nuclear export policies of major nations." 1981. *International Currency Review* 13:66-70.

O'DELL, P. R. and K. E. ROSING. 1983. *The Future of Oil.* London: Kogan Page Publishers.

OHASHI, T. M. and T. P. ROTH. 1980. *Privatization Theory and Practice* [Distributing Shares in Private and Public Enterprises]. Cases: BCRIC, Petrocan, ESOPs, GSOPs. Vancouver, B.C.: The Fraser Institute.

O'LEARY, Brian. 1975. "R&D: The thin edge of the wedge." *Bulletin of the Atomic Scientists* (October):9-14.

OLSON, McKinley C. 1976. *Unacceptable Risk: The Nuclear Power Controversy.* New York: Bantam Books.

ONTARIO HYDRO. 1981. Report #5955 (January). Toronto.

______. 1982. Report #620SP. See J.V.C. Fong et al. 1982. *Cost Comparison of CANDU Nuclear and Coal-Fuelled Generating Stations.* Toronto.

______. 1983*a*. Annual Report NGD-9. Toronto.

______. 1983*b*. Annual Report NGD-10. "Economics of CANDU-PHW." Toronto.

______. 1983*c*. Annual Report NGD-12. "World nuclear power reactor performance." Toronto.

"Ontario Hydro diversifies into tritum." 1983. *Nuclear Engineering International* (June):32-33.

ORGANIZATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT (OECD). 1982. *Nuclear Energy Prospects to 2000.* Report of the Nuclear Energy Agency and the International Atomic Energy Agency. Paris: OECD.

______. 1983*a*. "NEA Activities in 1982." Eleventh activity report of the Nuclear Energy Agency. Paris: OECD.

______. 1983*b*. "Nuclear Legislation – Canada." Nuclear Energy Agency. Nuclear Legislation Analytical Study. Regulatory and Institutional Framework for Nuclear Activities. Paris: OECD, pp. 37-52.

______. 1984. "Energy Statistics – Canada." International Energy Agency. Energy Statistics and Main Historical Series. Paris: OECD, pp. 22, 24.

______. 1985*a*. *Nuclear Third Party Liability and Insurance: Status and Prospects.* Nuclear Energy Agency and International Atomic Energy Agency. Proceedings of the Munich Symposium (September 10-14, 1984). Paris: OECD.

______. 1985*b*. *Nuclear Power and Public Opinion.* Report by the Nuclear Energy Agency Secretariat. Paris: OECD.

PALDA, Kristian S. 1984. *Industrial Innovation: Its Place in the Public Policy Agenda.* Vancouver: The Fraser Institute.

PAPPS, Ivy. 1975. *Government and Enterprise.* Hobart Papers #61. London: Institute for Economic Affairs.

PATTERSON, Walter C. 1976. *Nuclear Power.* Harmondsworth Mdsx, England: Penguin Books.

PEACOCK, Don. 1976. "Selling CANDU to Britain: A venture in public diplomacy." *International Perspectives* (January/February):3-8.

PEARCE, Fred. 1982*a*. "Critical time for Sizewell's reactor." *New Scientist* 95 (July 22):216-17.

______. 1982*b*. "Nuclear watchdog warns of Sizewell hazards." *New Scientist* 95 (July 15):139.

PERRY, Robert (ed.). 1977. *Development and Commercialization of the LWR, 1946-76.* Santa Monica, Calif.: Rand Corporation.

"Pickering shut down for tube test." 1983. *Nuclear Engineering International* (December):13.

"Point Lepreau goes independent?" 1983. *Nuclear Engineering International* (May):12-13.

PORTER, Arthur. 1978. (Chairman) "A race against time: Interim report on nuclear power in Ontario." Report of the Chairman of the Royal Commission on Electric Power Planning, Toronto.

______. 1980. *Report of the Royal Commission on Electric Power Planning: Concepts, Conclusions, and Recommendations.* Vol. 1. Toronto.

PORTER, Michael. 1980. *Competitive Analysis: Techniques for Analyzing Industries and Competitors.* New York: The Free Press.

POSEY, Carol. 1984. "On the Uranium trail." *The Atlantic* (June):22-24 and 29-30.

POTTER, William C. 1982. *Nuclear Power and Nonproliferation Technology and Economics of Nuclear Power.* Cambridge, Mass.: Oelgeschlager, Gunn and Hain Publishers.

PRICHARD, J. Robert S. (ed.). 1983. *Crown Corporations in Canada: The Calculus of Instrument Choice.* Ontario Economic Council. Toronto: Butterworths.

PRYKE, R. 1971. *Public Enterprise and Practice.* London: MacGibbon and Kee.

"Quadrupling of energy production costs predicted." 1984. *Oilweek* (July 23):8.

RAE, Bob. 1983. "Is free wheeling hydro insulated from reality?" *Globe and Mail.* National edition (October):7.

RAMO, Simon. 1980. *The Management of Innovative Technological Corporations.* New York and Toronto: John Wiley.

RIBICOFF, Abraham A. 1976. "A market-sharing approach to the world nuclear sales problem." *Foreign Affairs* 54 (4):763-87.

ROBERTSON, J.A.L. 1978. "The CANDU reactor system: An appropriate technology." *Science* 199, No. 4329 (February 10):657-64.

______. 1984. Brief to the Task Force on Federal Policies and Programs for Technology Development (March 14, 1984). Ottawa: AECL Research Company.

ROTH, Eli B. 1984. "Review of the state and nuclear power: Conflict and control in the western world, by J. A. Cammilleri." *Nature* 310 (July 26):342-43.

RYLE, Sir Martin. 1982. *Is There a Case for Nuclear Power?* London: Mernard Press.

SASSOON, E. 1982. "Japanese Policy for Energy and Raw Materials." *International Review of Economics and Business* 29 (December):1152-68.

SAYLES, Leonard R. and Margaret K. CHANDLER. 1971. *Managing Large Systems, Organizations for the Future.* New York: Harper & Row.

SCIENCE COUNCIL of CANADA. 1979. *Roads to Energy Self-Reliance.* Ottawa: Supply and Services Canada.

SHORROCK, Tim. 1982. "How the South Korean energy program has been saving the U.S. nuclear industry: U.S. taxpayers have paid, through Eximbank, $2.5 billion for Westinghouse sales." *Multinational Monitor* 3 (March):20-22.

SIMS, Gordon. 1979. "The evolution of AECL." M.A. thesis (unpublished). Carleton University, Ottawa.

______. 1981. *A History of the Atomic Energy Control Board.* Ottawa: Supply and Services Canada.

SLIGL, V. R. [Ontario Hydro]. 1982. "Cost comparison of 4 by 500-MW Coal-Fueled and 4 850-MW CANDU nuclear generating stations." *American Nuclear Society Transactions* 41 (1982), Supplement 1.

"Small CANDU is designed for export." 1983. *Nuclear Engineering International* (November):10.

SMART, Ian (ed.). 1982. *World Nuclear Energy: Toward a Crisis of Confidence.* The Royal Institute of International Affairs. Baltimore and London: The Johns Hopkins University Press.

SMITH, Derek. 1982. "A reactor designed for Sizewell." *New Scientist* 96 (October):236-39.

SMITH, Graham J. 1984. "Crown corporations and the marketing overseas of science and technology intensive goods and services: Brief observation on work in progress." Unpublished manuscript.

"South Korea plans to keep nuclear work." 1984. *Globe and Mail* (August 31):b4.

STEWART-PATTERSON, David. 1984. "Huge costs build up on AECL stockpile." *Globe and Mail* (August 20).

SWEET, Colin. 1983. *The Price of Nuclear Power.* London: Heineman.

SWIFT, Diana. 1983. "Nuclear medicine: AECL's lifesavers get a great reaction in world markets." *Canadian Business* 56 (May):21-22.

TAVEL, Charles. 1980. *The Third Industrial Age: Strategy for Business Survival.* 2nd ed. Translated by Donald C. Caldwell. Oxford: Pergamon Press.

"To Breed or not to Breed: Plutonium is the question." 1977. *The Economist* (October 15):22-23.

TOOZE, Sarah. 1982. "Modest advance (German nuclear power)." *Nature* 298 (August 26):793.

TREBILCOCK, Michael J. et al. 1982. *The Choice of Governing Instrument.* A study prepared for the Economic Council of Canada. Ottawa: Supply and Services Canada.

TWISS, Brian C. 1982. *Managing Technological Innovation.* 2nd ed. London and New York: Longman Group Limited.

UNITED STATES GENERAL ACCOUNTING OFFICE. "Questions on the future of nuclear power: Implications and trade offs." Washington, D.C.

UNITED STATES DEPARTMENT OF COMMERCE. 1982. "French reaffirm commitment to development of nuclear power." *Business America* 5, No. 21 (October 18).

UNITED STATES DEPARTMENT OF ENERGY. 1982. "Analysis of the Department of Energy's Clinch River Breeder Reactor Cost Estimates." Washington, D.C.

______. 1983. "Completing the Dept. of Energy's water-cooled breeder program." Report to Energy Research and Production, Committee on Science and Technology, House of Representatives. Washington, D.C.: U.S. General Accounting Office.

UNITED STATES NATIONAL ACADEMY OF SCIENCES, OFFICE OF INFORMATION. 1979. "Risks associated with nuclear power; a critical review of the literature." Washington, D.C.

UNITED STATES STANDING SENATE COMMITTEE ON NATIONAL FINANCE. 1984. *Federal Government Support for Technological Advancement: An Overview.* Report of the Honourable C. William Doody, Chairman. Washington, D.C.: U.S. Government Printing Office.

UNGER, Harlow. 1982. "Nuclear power struggles: The real casualty of ideological warfare is the truth." [American report]. *Canadian Business* 55, No. 6 (June):37.

VERNON, John M. 1971. *Nuclear Investment Planning in Civilian Nuclear Power.* North Carolina: Duke University Press.

VERNON, Raymond (ed.). 1974. *Big Business and the State.* Cambridge, Mass.: Harvard University Press.

VERNON, Raymond and Yair AHARONI (eds.). 1981. *State-Owned Enterprise in the Western Economies.* New York: St. Martin's Press.

WAKSTEIN, C. 1978. "The Windscale decision." *Political Quarterly* 49 (July):357-62.

WALGATE, Robert. 1984. "Overpowered [French nuclear energy]." *Nature* 311 (September):7.

WALKER, William and Mans LONNROTH. 1983. *Nuclear Power Struggles, Industrial Competition and Proliferation Control.* London: Allen and Unwin.

WEAVER, R. Kent. 1984. "Government enterprise in competitive markets." A paper for the Economic Council of Canada. Mimeographed.

WEBB, Ken. 1980. "Why nuclear energy? And is it safe enough?" *Canadian Geographic* 100, No. 4 (August/September):52-57.

WEINBERG, M. and I. SPIEWAK. 1984. "Inherently safe reactors and a second nuclear era." *Science* 224 (June 29):1398-1402.

"Westinghouse/Mitsubishi: Inbreeding." 1982. *The Economist* 282 (February 6):71-72.

"Westinghouse expects nuclear power revival." 1984. *Globe and Mail*, Report on Business (October 9).

WHITE, R. E. 1984. "The strategic management of commercially-oriented crown-owned companies." University of Western Ontario. London. Mimeographed.

WILLIAMSON, Oliver E. 1985. *The Economic Institutions of Capitalism.* New York: The Free Press.

WILSON, Richard. 1984. "Loose talk about nuclear power." *The Atlantic* (August):104-109.

"Windscale: Four million words later." 1978. *The Economist* 267 (March 11):72-73.

WINTER, R. K. 1978. *Government and the Corporation.* Washington: American Enterprise Institute for Public Policy Research.

WINTROBE, Ronald. 1984. "Public and private bureaucracies." A preliminary draft. Mimeographed.

WONDER, E. F. and R. W. MORRISON. 1970. "Canada's nuclear export policy." Norman Paterson School of International Affairs, Carleton University, Ottawa.

WONG, Stephen W. C. 1980. "CANDU export: Opportunities and challenges for Canada." *Energy International* 17 (February):11,12.

WOODWARD, Joan. 1965. *Industrial Organization.* New York: Oxford University Press.

"World list of nuclear power plants, operable, under construction, or on order (3 MWe and over) as of December 31, 1982." *Nuclear News* 26 (February 1983):71-90

WYMAN, Ira. 1985. "Failure at Seabrook could set off a chain reaction." *Business Week* (October):42.

WYNNE, B. E. 1982. "Rationality and revival: The Windscale inquiry and nuclear decisions in Britain." British Society for the History of Science, St. Giles, U.K. Monographs.

YOUNG, William H. 1984. "The saga of Clinch River." *Public Utilities Fortnightly* (August 2):11-20.

ZERBE, Richard O. Jr. (ed.). 1980. *Research in Law and Economics: A Research Annual.* Vol. 2. Greenwich, Connecticut: JAI Press Inc.

ZIMMERMAN, Martin B. 1982. "Learning effects and the commercialization of new energy technologies: The case of nuclear power." *Bell Journal of Economics* 13, No. 2 (Autumn):297-310.

ZUKER, Richard C. and Glenn P. JENKINS. 1984. *Blue Gold – Hydro-Electric Rent in Canada.* Economic Council of Canada. Ottawa: Supply and Services Canada.

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