NUCLEAR WASTE DISPOSAL AND DECOMMISSIONING: ARE COSTS TOO HIGH?

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By

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ABSTRACT

The great controversy surrounding the use of nuclear power as an electrical source has been further augmented by the problems associated with nuclear waste disposal and nuclear plant decommissioning. This paper focuses on the aspects and estimated costs of waste disposal and decommissioning. Comparison of cost estimates done by independent studies with those done by Ontario Hydro indicate that Hydro is grossly underestimating the costs of waste disposal and decommissioning. This result leads to the conclusion that Ontario Hydro is undervaluing the costs of nuclear waste disposal and decommissioning to justify its use of nuclear power in Ontario. Wide variations in cost estimates for decommissioning, and a lack of cost estimates for nuclear waste disposal, indicate that extensive research is needed in the discipline of cost estimation for waste disposal and decommissioning.

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CHAPTER 1

INTRODUCTION

The use of thermal generating stations for producing electricity in Ontario began in the 1960's, when electrical demand was still growing by seven percent a year, and when forecasters assumed that these rapid growth rates would continue in the future. At that time, Ontario Hydro relied mainly on water power for generation of electricity. Hydro believed the remaining undeveloped water power in the province could not meet the expected long-term demand for electricity. A new energy source was needed and thermal generating stations which used steam rather than falling water to turn turbines was the obvious source. To create this steam, oil, gas, coal, and above all, uranium would be used. Hydro believed that nuclear power would be cheap, clean, safe, and would replace Ontario's world dependency on fossil fuels.

Since the 1960's, thermal generation has not proven itself as an economically viable energy source. The public has also become deeply concerned about the environmental, health, and safety issues surrounding coal-fired and nuclear power. Environmentalists are opposed to coal for three reasons: open face coal mining procedures are a blight to the landscape; coal-fired plant emissions are significant contributors to acid rain and to air pollution in general; and the mining of coal contributes to black lung disease. Opponents of nuclear energy, on the other hand, envisage disaster due to both lack of safety in the plants, and the possible threat of nuclear arms proliferation. The greatest drawback to the use of nuclear power, however, is the resultant radioactive wastes that are produced. Large initial cash outlays are needed for containment and proper shielding of the wastes. Subsequent costly transportation and permanent storage procedures for the wastes will also be needed. Another major nuclear-related problem often overlooked is the decommissioning of older plants and the disposition of plant wastes, once a plant has reached the end of its design life. Nuclear plants no longer capable of generating electricity become a form of radioactive waste. A plant not dismantled immediately presents a long-term radioactive hazard.

One solution to the problems and uncertainties associated with nuclear waste disposal and decommissioning, is the change from large-scale, centralized energy technologies to a safe energy future based on conservation and renewable energy sources. Existing nuclear wastes need to be properly disposed of, and existing nuclear plants decommissioned; the time, money, and effort saved from not constructing future nuclear plants can be used to better develop possible solutions to these problems.

OBJECTIVES OF PAPER

The major objective of this paper is to examine the costs associated with nuclear waste disposal and decommissioning. The analysis is not aimed at developing precise numbers for these costs, since there is little past experience to draw on. The purpose is to compare different cost estimates with those from Ontario Hydro and answer why Hydro's estimates of waste disposal and decommissioning costs are so low relative to other estimates. The actual costs associated with waste disposal and decommissioning may be much greater than present estimates, and may affect the viability of nuclear power as an economically feasible energy source.

A secondary objective of the paper is to examine the total generation costs of coal-fired and nuclear powered stations. Of the present generation technologies in Ontario, CANDU nuclear and coal-fired plants are considered to be the major realistic options for large scale, base-load electrical generation. Different proportions of nuclear and coal-fired generation are possible and assessment of the relative economics of each is relevant (Canada, 1978). A number of total generation cost studies are presented to show that a disagreement exists between which electrical generation alternative, nuclear or coal-fired, is economically cheaper.

CHAPTER 2

STUDIES COMPARING GENERATION COSTS OF NUCLEAR AND COAL-FIRED STATIONS

INTRODUCTION

The total plant costs of generating electrical power are composed of two elements; capital or fixed costs and variable costs, including operation and maintenance costs, fuel costs, and financing costs. These classes of costs are significantly affected by the plant's output and average capacity factor. A brief description of each of these terms is found in Appendix A.1 Generating stations with high capital costs and low fuelling costs are more economic at high capacity factors (RCEPP, 1978). These are typically nuclear stations which are very expensive to build, but relatively inexpensive to operate. Generating stations with low capital costs and high fuelling costs are more economic at low capacity factors (RCEPP, 1978). These are typically coal-fired stations which are very sensitive to fuel costs. A one percent deviation from the projected annual rate of real escalation of the cost of coal means a ten percent difference in the lifetime generating cost of a new coal plant (Komanoff, 1981).

A comparison of existing estimates of generating costs presents numerous difficulties. First, changes in technology over time implies that studies carried out in different time periods are estimating the generating costs of different plants. A nuclear plant online in 1985 is not comparable to one online in 1975. Second, plant design is not similar within or between countries. The CANDU reactor in Canada is constantly being refined, and is very different from reactor designs elsewhere in the world. Third, cost comparison estimates of coal and nuclear plants may not be valid because different sets of assumptions have been used in producing the estimates. The assumptions used can make a substantial difference in cost estimates, and can ultimately dictate which source, nuclear or coal, is cheaper.

THE STUDIES EXAMINED

The study by the Royal Commission on Electric Power Planning (RCEPP, 1980) found that in terms of the economic costs of new base-load generation in Ontario, "nuclear generating stations are substantially more attractive than coal-fired generating stations", using a new 4 X 850 MW CANDU station and a new 4 X 750 MW coal-fired station with in-service dates of 1985. The RCEPP incorporated the following assumptions into their cost analysis: a 30 year design life (higher for nuclear plants); a discount rate of five and a half percent; and a mix of Canadian and U.S. coal. Figure 1 illustrates the economic costs of new nuclear and coal-fired generating stations coming into service in 1985. The figure shows that while the capital and operation and maintenance costs of a nuclear plant are higher by about 75%, annual fuel costs are only 20% of a coal-fired station. A nuclear station is cheaper for annual capacity factors higher than 25 percent over a 30 year period.

A sensitivity analysis was performed by the RCEPP to determine what deviations in variables would be required in order for coal and nuclear to be economically competitive at an annual capacity factor of 75 percent. The deviations required are: a 100 percent increase in nuclear capital costs; a 300 percent increase in the price of uranium; a decrease by more than 50 percent in the price of coal; and an increase in the real discount rate from 5.5 percent to 17 percent.

Banerjee (1980) substantiates the conclusions of the RCEPP while assuming the following: a station operating life of 30 years; in-service dates of 1985 for both plants; an average capacity factor of 70 percent; a 5 percent real discount rate; mid-point fuel price scenarios; and the best evidence on capital costs. Results estimate that nuclear plants will be 64 percent cheaper than coal plants. Strong and unrealistic assumptions have to be made in order for generating costs of coal and nuclear plants to be economically competitive. These assumptions include: a real discount rate of 17 percent; coal prices declining dramatically in real terms; an average capacity factor of 25 percent; and capital costs of nuclear being four times larger than the capital costs of coal.

Rossin and Rieck (1978) reported similar results for 6 nuclear and 6 coal-fired stations in the Chicago area owned by the Commonwealth Edison Company (see Table 1.1). The U.S. study compared the economics of each type of plant relative to average capacity factors and bus-bar costs (which are similar to generation costs found in the RCEPP and Banerjee studies). Bus-bar costs are considered to be the most important basis for comparing nuclear and coal stations. The bus-bar cost is the cost of delivering energy to the transmission system at the generating station bus-bar. The 1977 system average nuclear bus-bar generating cost was 13.3 mills/kW.h which was much lower than the system average coal-fired bus-bar cost of 24.1 mills/kW.h. Comparison of the 6 large nuclear plants and 6 large coal-fired plants also reveals a nuclear cost advantage (see Table 1.2). Corey's (1980) study substantiates results obtained by Rossin and Rieck indicating a cost advantage for nuclear power.

Hellman and Hellman (1983), however, reached a conclusion opposite to those mentioned above. Four nuclear cost estimates done by the Atomic Energy Commission (AEC), the Energy Research and Development Administration (ERDA), the Nuclear Regulatory Commission (NRC) and Exxon were presented. The authors adjusted these four case studies to arrive at their own estimates and found the total average lifetime bus-bar costs for coal-fired stations were 22 to 50 percent cheaper than nuclear powered stations. Hellman and Hellman claim a very wide gap exists between the design and actual performance of nuclear plants, which accounts for the difference in bus-bar costs. Lanoue's (1976) report substantiates results found by Hellman and Hellman (1983). In 1975, an Electrical World study showed that the average cost of electricity from coal-fired plants was 36 percent cheaper than the average cost of electricity from a nuclear plant. The actual bus-bar costs were 18.6 mills/kW.h for nuclear plants and 13.6 mills/kW.h for coal-fired plants.

Two additional studies on generating costs of coal-fired and nuclear stations are worthy of note since they appear to be the most comprehensive and extensive reports. These are Ontario Hydro's Report 620 and the U.S. based report done by Charles Komanoff.

The cost study by Komanoff (1981) has been purposely limited to the capital costs and total generating costs of new nuclear and new coal-fired plants, since results of the study found that capital cost increases, especially nuclear capital cost increases, greatly effect total generating costs. Results showed that cost estimates of new nuclear plants will be 20 to 25 percent greater on average than new coal plants in terms of lifetime generating costs.

This result holds true even when one considers assumptions beneficial to nuclear power such as improvements in the average capacity factor of present U.S. nuclear plants from the historical 54 percent average to 60 percent.

Komanoff argues that the main reason for the cost advantage of coal is the higher capital costs of nuclear. In 1971, capital costs of nuclear were 6 percent more than coal. In 1978, nuclear plants cost 52 percent more to build than coal plants with scrubbers, and 91 percent more than coal plants without scrubbers (it should be noted that coal plants in Ontario are not equipped with scrubbers). Capital costs account for two-thirds of the total generating costs for nuclear plants and one-third for coal-fired plants.

A major difference in Komanoff's (1981) study relative to others is the method used for estimating the costs of future nuclear and coal-fired plants. The engineering estimation cost method used by the power utilities is an analysis of design and construction changes that have contributed to past cost increases and those that can be anticipated to cause future increases. Komanoff argues that engineering estimates are adequate for assessing the costs of coal-fired plants but are unreliable for predicting nuclear costs. Continual engineering and regulatory changes cause presently operating nuclear plants to differ radically from original designs. Komanoff (1981) employs an etiological (underlying causal) estimation through development of a sector-size hypothesis which states that real increases in nuclear capital costs occur more or less in relation with the expansion of the nuclear generating sector.

The cost study by Ontario Hydro (1982), however, found that the lifetime costs of nuclear generation are lower than those of coal-fuelled generation for annual capacity factors above 21 percent, using a new 4 X 850 MW CANDU station and a new 4 X 500 MW coal-fuelled station, both with in-service dates of 1995 as a basis for comparison. Ontario Hydro incorporated the following assumptions into their cost analysis: a 40 year design life; a real discount rate between 4 and 5 percent; and a mix of Canadian and U.S. coal.

Hydro forecasts the total unit energy costs in constant 1982 mills/kW.h for 1995 plants at an average capacity factor of 80 percent. The total unit energy costs for nuclear were estimated to be 136 mills/kW.h which was much lower than the total unit energy cost of 156 mills/kW.h for coal-fuelled stations. Except for the initial one to three years after construction, the total unit energy costs for the nuclear generation alternative are much lower than those for the coal-fuelled alternative.

Results of a sensitivity analysis done by Ontario Hydro (1982) show that large changes in the cost estimates are required before the economic advantage of the nuclear option is lost. These changes include: a 47 percent decrease in the price of coal; a 262 percent increase in the price of uranium; and a 190 percent increase in nuclear capital costs. Higher discount rates also reduce the economic advantage of the nuclear option.

Based simply on the number of cost studies presented, it would appear that there is a nuclear cost advantage, although by no means is there unanimity in this conclusion. Ontario Hydro's (1982) estimates are substantiated both by a U.S. study done by Rossin and Rieck (1978) and one by the RCEPP (1980), who used similar assumptions to Hydro's. The latter is a commission set up directly by the federal government to examine energy related issues in Canada. The cost studies showing a coal advantage involve U.S. nuclear reactors which are much different in design than CANDU reactors. The cost estimates done by Hellman and Hellman (1983) are based on their adjustments of original estimates done by the AEC, the ERDA, the NRC, and Exxon. In many cases, these adjustments doubled the original estimates, which raises questions as to the validity of this study.

SNYNOPSIS

Decisions as to which type of plant to use, coal-fired or nuclear, cannot be based on economic comparisons alone. The "hidden costs" of nuclear power, namely, nuclear waste disposal and decommissioning must also be examined and added to total generating costs. Only then is it possible to assess the total costs of nuclear power. The great uncertainty, however, surrounding decommissioning and waste disposal costs estimates, makes this assessment extremely difficult.

CHAPTER 3

NUCLEAR PLANT DECOMMISSIONING

Introduction:

One important aspect of nuclear power is the question of what to do with the nuclear plant once it has reached the end of its design life. The International Atomic Energy Agency (IAEA) (1979) has found that once a nuclear reactor has outlived its generating capabilities, it cannot simply be left alone or salvaged for scrap, because the structural materials (mainly metal and concrete) are highly radioactive. Harwood et al. (1976) have recognized that each large nuclear power plant in operation today may be radioactively hazardous for a million years. The problem of radioactivity in the reactor and the surrounding building is quite different from the more publicised problems of radioactivity created in the fuel or cooling water. During operation of a nuclear plant, the uranium fuel undergoes fission; the uranium atoms split, releasing neutrons, some of which split other uranium atoms. Heat is then produced which creates electricity and radioactive wastes. Some of these wastes remain radioactive for centuries, leading to the issue of permanent waste disposal (discussed later in the paper). Some of these neutrons pass into the steel structure, the cooling water, the steel vessel which holds both the fuel and cooling water, and even into the concrete shielding outside the reactor. The neutrons are eventually absorbed by atoms of iron, nickel, and other elements in steel, water, and concrete. Elements radioactive due to neutrons emitted by the reactor fuel are called "activation products". The waste products of the fuel itself are called "fission products". When a reactor is shut down, the highly radioactive fuel or "fission products" can be removed for storage. Radioactive "Activation products", however, remain in the reactor, reactor vessel, and concrete shield. These components of the nuclear facility must be shielded from man and the environment. It should be noted that there are considerable differences in the volumes of "activation products" in different reactors. Harwood et al. (1976) assumes that the volume of "activation products" is proportional to the energy produced by the reactor. Given the problem of radioactivity in nuclear reactors and the different volumes of radioactivity that occur in different plants over their lifetime, what solution can be used to solve this problem? Ontario Hydro (1981) defines the process of removing a nuclear facility from service at the end of its useful life, and transforming it into a safe and acceptable out-of-service state as decommissioning.

<u>Types of Decommissioning</u>:

Decommissioning can occur in three forms that are internationally recognized: mothballing, encasement or entombment, and dismantlement (IAEA, 1975). Studies such as Staats (1977) and Quiqq (1983) incorporate a fourth form of decommissioning; a combination of either entombment or mothballing with eventual dismantlement. All forms vary in costs, time, surveillance, monitoring, and the amount or volume of radioactive materials left in the structure. The IAEA (1975) recommends that all forms involve minimal radiation exposure to man and the environment, and no carry over of responsibility to future generations. Unsworth (1979) describes the procedures for each of the first three decommissioning methods.

Mothballing:

Mothballing is simply the removal of all spent fuel from the reactor and all irradiated fuel from used fuel bays. The facility is placed in protective storage because the primary containment (piping and equipment associated with the primary cooling units) and the secondary containment (the nuclear facility) are maintained intact. The facility will require surveillance and monitoring for security reasons and for possible radiation leaks of both the primary and secondary containment systems as well as periodic maintenance. Mothballing involves the lowest capital expense but the greatest operating expense of the decommissioning methods (Harwood et al., 1976).

Encasement:

Encasement involves removal of all components that are radioactive to the extent that they will remain a health hazard longer than the life of the proposed encasement structure, assumed to be less than 100 years. The facility is then sealed with concrete or steel. Surveillance is then needed to detect possible radiation leaks due to deterioration of the encased structure with age.

Dismantlement:

Dismantlement is the most complete and expensive method of decommissioning. It involves the total removal of the facility from the site. The land is then restored to its original condition and released for unrestricted use. After station removal is completed, no further surveillance, inspection, or tests are required. The largest problem involved with dismantling is preventing workers in the dismantling process from receiving large doses of radiation (Staats, 1977). The cutting of the reactor parts must be done by remote-controlled equipment, sometimes underwater. Although dismantlement is the most expensive and time consuming method of decommissioning, the advantage over other methods is that the site becomes reusable and, therefore, the value of the site is a credit against the cost (Unsworth, 1979).

Dismantlement appears to be the only form of

decommissioning that will ensure public health and safety. Mothballing or encasement removes only some of the radioactive components and then the plant is sealed and monitored for radiation leaks. According to Nuclear Regulatory Commission (NRC) regulations, this presents unacceptable radiological hazards. The "activation products" must remain inaccessible to the public until they decay to safe levels. For this reason, mothballing or encasement are not regarded as permanent decommissioning methods.
The NRC does, however, permit utilities to use any one of the decommissioning procedures. Andre Cregut, head of France's decommissioning problem believes that total dismantlement is essential (New York Times, 1978), while Solomon and Cameron (1984) believe plants not dismantled immediately provide a longer term hazard of residual plant radioactivity. Mothballing or encasement are interim methods which are cheaper but not permanent, and do not ensure safety to the public.

Dismantling Present Reactors:

Shut down nuclear reactors such as the Gentilly-1 in Canada and the Shippingport and Three Mile Island reactors in the U.S., could provide excellent experience and insight into the dismantling procedure. Edwards (1983a) argues if the Canadian nuclear industry does not develop the technology needed to decommission CANDU reactors, there could be a large burden on future generations. To prevent this situation, dismantling of the 250 MW Gentilly-1 reactor should be done as soon as possible. Since the Gentilly-1 reactor was in operation for less than 7 months, the amount of total radiation will be much less than commercial reactors operating for 25 to 30 years. Less of a health hazard will be present for workers during the dismantling process. Robotic equipment, such as remote-controlled cutting torches which will be needed to dismantle larger reactors, can be field tested at Gentilly-1. If this equipment is successful, it could make Canada a world leader in robotic nuclear dismantlement. There is also the possibility of non-nuclear technological spin-offs that could result from the technological development of robotic equipment.

Gentilly-1, Shippingport, and Three Mile Island, present three different dismantling procedures that will offer insights into the potential problems and costs of dismantling. Gentilly-1 will provide a good base case for dismantling, because mistakes caused by inexperience will be less hazardous to workers due to less radiation exposure (Edwards, 1983a). Shippingport, due to its longer generating life of 25 years, will offer valuable insights into the actual costs and problems that accompany dismantlement. Finally, Three Mile Island will give insights into the costs and problems of dismantling nuclear plants that are near melt-down.

Uncertainties in Cost Estimation:

Since no commercial nuclear reactor has ever been dismantled, cost estimates must be based on experience with small experimental reactors or on conceptual studies of decommissioning conventional plants (Komanoff, 1981). IAEA (1979) mentions 65 reactors decommissioned since 1960, but most have only been mothballed or encased without actually being dismantled. Thus, there are many uncertainties involved in estimating or predicting future decommissioning (primarily dismantlement) costs. Ontario Hydro (1981) mentions a number of uncertainties which could effect the costs of decommissioning. Improvements in technology, engineering methods, and materials would tend to reduce estimated costs. For example, equipment for cutting thick reactor vessels has not yet been fully developed (Kamanoff, 1981). Location of a waste disposal facility near the nuclear plant could decrease the estimated costs as well. Changes in regulations governing dismantlement, transportation, and disposal would tend in general to increase costs. Increases in the length of the storage with surveillance period would also tend to increase the costs. Changes in long term interest and cost escalation rates could either increase or reduce estimated costs. Finally, plants currently under construction may contain far more equipment and structure and thus require more effort to dismantle, again increasing costs.

Costs of Decommissioning:

Dismantling plants in the U.S. and Canada may indicate that costs of decommissioning will be higher than previously estimated. These "hidden costs" may be detrimental to the use of nuclear power in Ontario. According to Komonoff (1981), only two U.S. reactors have been completely dismantled to date. They are the 20 MW Elk River BWR plant in Minnesota and the 10 MW Sodium Reactor Experiment near Los Angeles. Neither of these are similar to today's commercial reactors in terms of radioactivity accumulated and size of the reactor core. Accordingly, these plants should be easier to dismantle relative to commercial plants today. The Elk River Reactor, however, cost $6.9 million to dismantle but had construction costs of only $6 million. This ratio suggests that dismantlement of present nuclear reactors in operation may be very expensive relative to initial capital costs. The ratio also suggests that costs of decommissioning nuclear plants may be grossly underestimated. Actual decommissioning costs of plants may make nuclear power as an energy-source not viable.

Cost Study Estimates:

Many cost studies regard decommissioning costs (particularly dismantling costs) as uncertain and range from 3 to 100% of the original capital costs, or as much as $1 billion per reactor. Ontario Hydro's decommissioning cost estimates are in the lower portion of the range (see Table 2.1). Decommissioning costs of the Pickering "A" and Bruce "A" nuclear stations are estimated to be approximately 10% of the original construction costs, far less than other estimates.

The significant assumptions used by Hydro (1983) in estimating future costs of decommissioning a 4 X 850 MW nuclear plant are: a decommissioning procedure on the deferred dismantlement basis where costs are based on a 40 year operating life and a 39 year decommissioning period; a transportation distance of 1600 km's from nuclear generating facilities to disposal facilities; and interest and escalation rates through to the completion of decommissioning averaging 8% and 6.6% respectively. Hydro (1982) estimates the total annual costs of decommissioning a nuclear plant for a 1995 in-service date to be $8 million or $2.4 per kilowatt hour. This cost remains constant over the station's 40 year life. Other estimates of nuclear decommissioning costs are presented in Tables 2.2 and 2.3.

All but one of the studies do not reveal what decommissioning procedures are involved in their cost estimates, which makes comparisons with Hydro's estimates extremely difficult. Unsworth's (1979) cost estimates are for a 6 year plant dismantling and removal procedure. The reactor site is backfilled and graded, and released without restriction for other uses. It is assumed that the \$41 per kilowatt hour estimate by the Nuclear Regulatory Commission is for mothballing, the cheapest form of decommissioning. The higher cost estimates are assumed to be for dismantling, the most expensive procedure.

Although comparisons are difficult, it would appear, based on the cost estimates, that Ontario Hydro is grossly underestimating decommissioning costs. Other evidence reveals that Hydro's estimates for decommissioning are extremely low. First, relatively simple repair and maintenance procedures such as replacing sections of piping, already cost millions of dollars due to difficulties from working in radioactive environments (Harding, 1978). Secondly, the NRC study and other U.S. studies are based on the dismantling costs of the Elk River Reactor. These studies are underestimating decommissioning costs because, as mentioned previously, the dismantling costs of the Elk River reactor were larger than the construction costs. Finally, the recent accident at the Pickering nuclear power plant may dictate how expensive decommissioning procedures will be (Edwards, 1983b). It may be necessary to replace all 390 tubes in each of the plant's four reactors. The Canadian nuclear industry's retubing cost estimates are \$80 million per reactor, for what is in effect a mini-decommissioning job lasting a year and requiring sophisticated new robotics equipment.

Who Pays For Costs?

Different approaches can be used to pay for costs of decommissioning today, rather than placing a burden on future generations (Staats, 1977). One is a direct charge to users or customers through electricity rates. These funds are then deposited into a trust fund. A second approach involves recovering the cost of decommissioning nuclear reactors through depreciation accounts. A third approach is a bonding arrangement to protect the government from paying for the costs in case utilities are not able to decommission their plants. Most utilities are gathering revenue on the basis of 10 to 15 percent of construction costs (Holmes, 1984). If they have underestimated decommissioning costs, taxpayers and electricity consumers will have to pay the costs, and the economics of nuclear power will have been questioned.

Staats (1977) did a survey of all companies in the U.S. operating uranium mills and fuel fabrication plants and all utilities with operating or planned nuclear reactors. Only 3 out of 11 companies with operating mills are providing some form of bonding and only one firm has established a fund for future decommissioning. Seventeen out of 32 utilities use depreciation accounts to take account of future decommissioning costs which are reflected in utility rates. These extra charges are usually used to pay off existing debts of the utilities, however. The utilities expect to pay eventual decommissioning costs when they occur. The other 15 utilities are doing nothing to accumulate funds for decommissioning. Ontario Hydro (1981) charges amounts for the estimated liability for decommissioning a nuclear plant into a liability account. The annual provisions over the remaining life of the nuclear facility, together with interest on accumulated balances, recover the estimated future decommissioning costs. A survey done by Ontario Hydro shows the accounting practices of other utilities in Canada to pay for future decommissioning costs. Twenty-four utilities responded to the survey. Of these, 63 percent charge current customers for future costs of decommissioning. It is likely that utilities will underestimate decommissioning costs, placing a burden on future generations to pay for these costs.

Synopsis:

While decommissioning costs alone are unlikely to limit the growth of nuclear power, such costs when added with those for waste disposal, could make nuclear power very expensive. It appears that U.S. and Canadian public utilities are placing much of the burden of the costs of decommissioning on future generations by their choice of decommissioning procedure. The difficulties and higher dollar costs associated with immediate dismantlement would seem to point toward deferment of dismantling the most highly radioactive parts of the reactor as the decommissioning procedure to be used by utilities.

CHAPTER 4

NUCLEAR WASTE DISPOSAL

Introduction:

Nuclear generating stations produce a number of radioactive materials that must be carefully handled, stored, and ultimately isolated from man and his environment. The most radioactive of these wastes is irradiated fuel, but the greatest concentrations of wastes are uranium tailings. Radioactive waste is defined as any material containing, or contaminated with, radionuclides in concentrations greater than would be considered acceptable for uncontrolled use or release, and for which no further use can be foreseen (Energy, Mines, and Resources (EMR) (1984)). Policies concerning the proper management of these wastes must be undertaken since these radioactive wastes present a potential hazard to man and the environment.

There are two types of nuclear waste management; storage, which is interim, and disposal, which is permanent. The distinction between disposal and storage is crucial (Aikin, 1980). Storage implies retreivability of nuclear wastes. They are temporarily contained and isolated until another use is found for them. Storage also implies surveillance, monitoring, and security for safety and environmental protection. Disposal implies placing the wastes in a repository with no intention of recovery.

The objective is to isolate the wastes from man and the environment forever, without the need for surveillance or monitoring. Most of the radioactive wastes at present are in storage. Surveillance and monitoring is thus needed to ensure that hazardous amounts of radioactive wastes are not exposed to man or the environment. The ultimate goal of waste management is the transition from storage to disposal.

Due to reactor operation, the waste products or "fission products" of the fuel are highly radioactive (Harwood et al., 1976). Since this fuel is highly radioactive and continues to generate heat, it must be shielded by immersing it in water. Ontario Hydro (1983a) stores all irradiated fuel in water-filled bays at the nuclear facility. These fuel bays have enough capacity to safely store all production of irradiated fuel by Ontario Hydro well into the 1990's. Interim storage of irradiated fuel, however, is not regarded as a permanent method of managing nuclear wastes. Interim storage is regarded as an economic, efficient, and safe system of handling nuclear wastes until the techniques for permanent disposal have been developed.

Types of Nuclear Wastes:

Most of the radioactive wastes are produced in the nuclear fuel cycle, which begins with the extraction of uranium ores from rock, and ends with the disposal of fission products and depleted uranium (Aikin, 1980). This cycle has a sequence of stages, each producing different radioactive wastes. Table 3.1 shows these stages with the accompanying wastes listed (see Appendix C). Nuclear wastes can be broken down into three categories: uranium mining and milling wastes; reactor wastes; and irradiated fuel wastes (Aikin, 1980 and Boulton, 1978). Each one of these categories poses different problems in terms of handling, radiation emitted, and volume. All of these wastes must be disposed of in such a way as to limit the potential radiation risks to man and the environment (see Appendix C.1).

Uranium Mining and Milling Wastes:

Most commercial mining involves ores containing less than one percent uranium (Aikin, 1980). Extraction of uranium in the milling stage produces large volumes of wastes called uranium tailings. At present, there are 150 million tonnes of tailings in Canada covering a total area of 10 square kilometers (EMR, 1984). Uranium tailings are usually stored in huge outdoor piles, called tailing ponds, which can be blown by the wind or washed by the rain (Edwards, 1983). Uranium tailings are highly toxic and will remain hazardous for thousands of years (Landa, 1980). Most of the radioactive isotopes in tailings such as Radium-226 emit alpha radiation. These radionuclides are hazardous to to man only if taken into the body by eating, drinking, or inhaling (Boulton, 1978). Measures must therefore be taken to control possible movement of tailings to water systems and the air. Scientific evidence has shown that even small doses of radiation emitted by tailings can cause cancer.

Since uranium tailings present a potential radiation hazard to man and the environment, methods need to be devised to dispose of these wastes in a safe manner. All methods aim at physical stabilization of the wastes and limits on wind and water erosion (Aikin, 1980). Due to the large volumes of tailings, however, many of these methods are costly and difficult. Revegetation of the tailings appears to be an optimal method of disposal. This method involves planting grass on top of tailings after they have been dumped directly onto the land surface. Revegetation makes the dumps look better and will enhance the short term physical stability of the tailings dump against wind and water erosion (Torrie, 1982). Planting grass, however, on top of tailings which remain radioactive for thousands of years will not be sufficient for long term prevention of erosion (Torrie, 1982). Thus, alternative methods have been proposed. One is putting the solid wastes back into the mine from which they came, called mine back-filling. Only half of the tailings, however, can be handled this way due to their large volumes, and back-filling may interfere with present mining operations. Another method for storage of tailings is deep lake disposal. If lakes are located close to the mining operations such as the Elliot Lake mine, it is possible to deposit the tailings into these lakes. The only danger associated with this method is the possibility of a deep channel flowing out of the lake which will transport the tailings. Dumping of tailings into lakes, however, could have major effects on the surrounding ecosystem. For example, the Serpent River, near Elliot Lake became contaminated with radioactive radium, acidity, ammonia, and other toxic pollutants from the tailings. As a result of this contamination, there are no fish living in the Serpent River for fifty-five miles downstream (OPIRG, 1981). Efforts to improve tailings management include the establishment of treatment plants to trap the radium, and the use of lime to neutralize the acidity in wastes.

Uranium tailings may turn out to be one of the major drawbacks to nuclear power. No agreed upon method has been developed for disposing of tailings and costs for disposal may be very high. For example, the cost for disposing of tailings in Elliot Lake range from $30 million (CCNR, 1980) to $18 billion (NRC, 1974). British Columbia has even imposed a seven year ban on uranium mining due to public pressure and concern about the effects of mining on the environment and the health of miners.

Reactor Wastes:

Reactor wastes are all the radioactive wastes resulting from the operation of a nuclear plant, excluding the irradiated fuel (Aikin, 1980). Neutron activation reactions in the reactor core produce two types of reactor wastes, solid and liquid (Boulton, 1978). Solid wastes are materials that are contaminated from cleaning and conditioning the reactor coolant and moderator and the fuel storage bay water. These materials contain high levels of radiation which must be shielded when handling. Liquid wastes are materials contaminated by contact with the reactor system during operation and maintenance. These materials consist of protective clothing and cloth wipers which contain little radioactivity. Reactor wastes are generally not a long-term hazard and methods of handling and storing of these wastes are well-developed, safe and economical (Carter and Mentes, 1976). For example, at the Bruce nuclear station, the solid wastes are burned in an incinerator while liquid wastes are placed in concrete bunkers above the water table (Aikin, 1980).

Irradiated Fuel Wastes:

The largest quantities of radioactivity produced in the nuclear fuel cycle are contained within the irradiated fuel. This fuel is currently being discharged from CANDU reactors at a rate of about 1000 tonnes per year

(EMR, 1984). Most of the radioactivity in the irradiated fuel is due to "fission products" for the first few hundred years. After this period, "activation products" become the main source of radioactivity in the fuel. Many of the isotopes of the "activation products" have very long half-lives and remain radioactive for hundreds of thousands of years. The shorter-lived "fission products" emit gamma radiation and beta particles, while the longer-lived "activation products" emit alpha particles (Boulton, 1978). The problem facing Ontario Hydro is the need for new storage capacity because the present storage water bays are reaching their holding capacity (Aikin, 1980). There is also concern over the proper disposal of "activation products" which can remain a radioactive hazard for thousands of years. The concept of permanent disposal is a solution to filled storage bays and long-lived radioactive elements.

In 1978, the federal government and the government of Ontario reached an agreement under which the responsibility for research and development work on the storage and transportation of irradiated nuclear fuel was Ontario Hydro's, while the Atomic Energy of Canada Limited (AECL) would be responsible for research and development work on nuclear fuel waste immobilization and ultimate disposal (EMR, 1984). The most suitable method now being examined by AECL for permanent disposal of nuclear fuel wastes is to deposit them inside hard rock formations known as plutons.

A pluton is a large underground mountain of rock, often many kilometers in diameter, formed from cooling molten magma inside the earth's crust (EMR, 1984). Thousands of plutons have been identified in the Precambrian Shield which is one of Canada's oldest and most stable geological formations. Disposal involves drilling into these plutons, and inserting the wastes. The wastes would be surrounded by various barriers designed to isolate the radioactivity from the environment.

Many questions, however, remain to be answered before disposal in plutons is proven to be safe. First, an acceptable waste disposal method must be able to isolate highly-radioactive wastes, perfectly, for hundreds and even thousands of years. One scientist argues that waste disposal must accomplish the impossible, 99.999 percent containment for 250,000 years. This is the length of time necessary for the plutonium-239 in the waste to lose half of it's initial radioactivity (OPIRG, 1981). Secondly, over the centuries anything can happen. Civilizations can rise and fall. It is thus impossible to guarantee the proper care of a waste disposal site. Thirdly, there are questions concerning the long-term stability of the rock. There is the possibility that rock as solid as the Canadian Shield may shift and crack, releasing radioactivity. Fourthly, there is the question of transporting wastes from the reactor site to the disposal facility. Currently, there are 100 shipments a year of spent fuel in the U.S. Radioactive waste shipments on the highway at any given time could increase one hundred fold over the next 15 years (Resnikoff, 1983), and the risk of waste spillage during transport will rise, perhaps dramatically. Finally, assuming a safe waste disposal method is devised, a major question remains on the disposal location. Wherever a waste disposal site is built, neighbouring residents will have to live with fears of waste spillage during the transportation and unloading stages. They will also have to live with fears of long-term leaching of radioactivity from the disposal site.

Uncertainties in Cost Estimation:

There are many uncertainties involved in estimating or predicting future nuclear waste disposal costs. Ontario Hydro (1981) mentions a number of uncertainties which could effect the costs of waste disposal. First, improvements in technology, engineering methods and materials would all tend to reduce estimated costs. Secondly, the location and in-service date of a storage facility and repository would tend to increase estimated costs the more remote the location from reactor sites (increase in transportation costs) and the earlier the in-service date. Ontario Hydro uses the year 2000 as the minimum in-service date of a disposal facility, since water bays located at site can safely store wastes until this time. Thirdly, if reprocessing of irradiated fuel occurs, this will tend to reduce estimated costs. Since Canada has at present ample resources of uranium to fuel nuclear reactors, reprocessing may not be undertaken until a future time when depletion of resources may occur (Boulton, 1978). Fourthly, changes in the regulations governing the transportation and disposal of irradiated fuel could tend to increase estimated costs. Finally, changes in long term interest and cost escalation rates which could either tend to increase or decrease estimated costs. It should be noted that Hydro presents uncertainties with the costs of disposing irradiated fuel. It fails to mention costs estimates associated with uranium tailings which, as mentioned previously, may be very expensive. Inclusion of these estimates by Hydro, may increase nuclear waste disposal costs estimates significantly.

Cost Study Estimates:

Cost estimates for nuclear waste disposal are very difficult since no internationally accepted method has been decided upon. Geological disposal, the present proposal in Canada, will not be operational for at least 20 years, and some scientists question the concept of depositing wastes into hard rock formations. CANDU nuclear reactors, however, will be producing approximately 1800 metric tonnes of waste a year that will eventually require permanent disposal (Financial Post, April 25, 1981). The costs of new interim storage facilities will be required to handle the large amounts of waste until a method for permanent disposal is in operation.

Ontario Hydro (1982) estimates the irradiated fuel management costs for a new 4 X 850 MW nuclear station to be \$64/kgU in 1979 dollars. The significant assumptions used by Hydro were: an in-service date of the year 2000 for irradiated nuclear fuel disposal facilities; a transportation distance of 1600 km from generating facilities to disposal facilities; and interest and escalation rates through to the disposal date, averaging 9.3 percent and 7.3 percent respectively.

Other estimates of nuclear waste disposal costs indicate that Hydro is probably underestimating costs of waste disposal. The lack of estimations is an indication of the difficulties involved in cost estimation of waste disposal. Komanoff (1981) estimates the costs of permanent disposal to be \$652/kgU in 1979 U.S. dollars. This figure is much higher than the cost estimated by Hydro. Banerjee (1980), on the other hand, estimates the cost of waste disposal to be \$17/kgU in 1986 dollars. A contingency factor of 66 percent was added to this cost to reflect the uncertainty surrounding geological disposal. The estimate by Banerjee is much lower than Hydro's estimate for permanent disposal. Thus, the accuracy of this estimate is questionable, since Hydro is probably underestimating permanent waste disposal costs. A study by the Department of Energy (1982) estimates the costs of geologic disposal to be $350/kg.U in 1980 Canadian dollars, which is also much greater than Hydro's estimates.

It is difficult to draw valid conclusions about the costs of permanent waste disposal, due to the lack of estimates. Based on the estimates given, it would appear that Hydro is underestimating nuclear waste disposal costs. The range of these estimates, from $17 to $652 a kg begs the question whether the studies are measuring the cost of the same permanent disposal method. Komanoff's $652 estimate includes a portion of government regulation and research and development costs and added contingencies due to the uncertainty surrounding permanent disposal methods. Banerjee's estimate includes an added contingency but is still probably overly optimistic. Hydro includes no contingencies at all in their cost estimate. The question to be answered is whether the costs of waste disposal will affect the assumed nuclear cost advantage, as previously mentioned in Chapter 2. Hydro (1982) estimates the costs for irradiated fuel management to be $3.3 mills/kW.h based on disposal costs of $64/kgU. If one reasonably assumes that Hydro's estimates are incorrect, and actual costs of permanent disposal reflect the middle part of the range of estimated costs, waste disposal costs when added with decommissioning costs could make nuclear power very expensive relative to alternative forms of energy.

Who Pays For Costs?

One of the major questions concerned with nuclear waste disposal is the economic cost and risk assessment associated with it (Skinner and Walker, 1982). Value judgements are needed to decide if current or future populations are going to pay for the costs of wastes already produced and methods of disposing of them. The problem of who pays for these costs is compounded by the fact that these costs will not be required for at least 20 years (Hydro's minimum in-service date of a disposal facility).

Ontario Hydro will incur costs for all future irradiated fuel management operations. Hydro recommends that an amount of 0.60 mills/kW.h be charged to current electricity consumers to cover future transportation and disposal costs for irradiated fuel in 1983 (Ontario Hydro, 1982). Accounting practices of 23 other North American and European utilities who are responsible for disposal of their nuclear fuel, indicates that 70 percent of these utilities charge or intend to charge current customers for future costs of disposal of irradiated nuclear fuel. The other 30 percent intend not to charge current customers. As is the case for decommissioning costs, utilities will likely underestimate nuclear waste disposal costs, placing a burden on future generations to pay for these costs.

Synopsis:

Extensive research should be done immediately on the techniques needed for the ultimate disposal of irradiated fuel and uranium tailings, since the results may have a decisive influence on the future of nuclear power. During 1979, however, only $16 million out of a total AECL budget of $250 million was spent on waste research (Ontario, 1978/81). Almost nothing was spent on tailings disposal research. It appears that public utilities, such as Ontario Hydro are more concerned with promoting the nuclear industry rather than funding research projects to solve the problems, namely, waste disposal, of the industry. Nuclear waste disposal and uranium tailings must be regarded as a serious problem in order to develop possible solutions for them.

CHAPTER 5

NUCLEAR WASTE DISPOSAL AND DECOMMISSIONING ALTERNATIVES

Introduction:

The Ontario government has promoted nuclear electricity as a substitute for fossil fuels now being imported into the province. They argue that nuclear power would keep money and jobs in Ontario and increase our energy security. Should the people of Ontario believe Ontario Hydro's argument for nuclear power as the main electrical energy source? There are great possibilities that nuclear power may be prohibitively expensive, due to the high estimated costs of nuclear waste disposal and plant decommissioning. There are also great environmental and health risks associated with nuclear wastes, in particular, uranium mine tailings. What alternatives are avilable to nuclear power? Conservation and renewable forms of energy accomplish the same economic goals the Ontario government believes nuclear power has, at less cost and greater energy security. Conservation and renewables are also more environmentally appropriate, and above all, would diminish the risks and uncertainties associated with nuclear waste disposal and plant decommissioning. If additional electrical sources are needed due to increased demand, undeveloped hydro power and industrial co-generation could be used. Both of these electrical sources compare favourably with nuclear power (OPIRG, 1981)

Conservation and Renewables:

A conserver society functions on renewable sources of energy (such as the sun and the wind) and is composed of recycled materials. It is also pollution free and protective of the environment. Conservation means not wasting energy but being energy efficient. According to a report by the Royal Bank, two reasons why Canadians waste energy are because oil, natural gas, and hydro power have been so cheap relative to other countries, and because government price subsidies favour energy intensive rather than energy saving industries (OPIRG, 1981). Canada uses about three times as much energy per person as Japan and twice as much as West Germany. Both of these countries produce almost twice the goods and services that Canada produces per unit of energy consumed.

Conservation makes economic sense because the extra cost of installing insulation or improving the efficiency of a manufacturing process is soon repaid in reduced energy costs. If half of the $7 billion proposed to be spent on the Darlington nuclear site was spent on home insulation, more energy for heating would be saved than Darlington would produce in its generating lifetime (OPIRG, 1981).

Two major advantages of introducing serious conservation and efficiency improvements in Canada are: a reduction in the need for multi-billion-dollar energy projects;

and benefits associated with recycling. Reducing the need for large-scale energy projects would free up capital for other useful and productive investments such as conservation measures. The nuclear industry in Canada has consistently had the greatest share of federal funds for energy research and development (see table 4.1). Recycling reduces the need for continued production of raw materials, reduces the volume of wastes, and contributes to reductions in air pollution. Chem-Ecol Ltd. recycles over one million gallons of waste oil per year, and returns it to oil companies at half to two-thirds the cost of new oil.

A study by EMR (1983) concludes that it would be technically feasible and cost-effective to operate the Canadian economy in year 2005 with 12 percent less energy than it required in 1978, and, over this period, to shift from 16 percent reliance on renewable resources which includes hydro-electric power to 77 percent reliance.

Hydro-Electric Power:

Ontario Hydro has argued that there is no undeveloped hydro power left to be exploited in the province. A report by Hydro's own Hydraulic Development Section lists 8700 megawatts of undeveloped hydro power in Ontario. The report lists a further 4650 megawatts of undeveloped pumped storage. Pumped storage is a way of storing surplus power during off-peak periods and making use of it when demand is high. If the assumed growth in electrical demand is less than 1.5% annually, demand from 1981-1990 for electricity could be met entirely with small-scale hydro-electric plants (Lonergan, 1985). Seventeen hydro sites identified by Ontario Hydro could be built at much lower cost than the equivalent nuclear capacity (OPIRG, 1981). The environmental impact of these projects would be small since each project is relatively small-scale.

Industrial Co-Generation:

A number of countries use industrial co-generation as an electrical source (almost one-third of electricity generated in West Germany is through co-generation), however, co-generation is a relatively unknown electrical source in Ontario. Co-generation is the combined production of industrial process steam and electricity at the same time. Industries such as steel, pulp and paper, chemicals, and petroleum use a great deal of high temperature steam for use in manufacturing processes. With co-generation, the steam could be used twice; once to turn a turbine to generate electricity, and once to process heat. The result is a dramatic improvement in energy efficiency.

In Ontario, there is about 500 MW of installed co-generation capacity, the equivalent of one Pickering sized nuclear reactor. The Dow Chemical plant in Sarnia generates all its own electricity through co-generation techniques and has a surplus left over to sell. An additional 2100 MW of co-generation capacity could be installed in Ontario by 1990 (the same time the 3500 MW Darlington station is scheduled to come into service). The capital costs of installing industrial co-generation capacity are lower than the costs per kilowatt of building new coal-fired or nuclear stations. Co-generation plants are also about twice as energy efficient as Ontario's thermal generating plants.

Construction of additional nuclear plants is questioned since Ontario Hydro has experienced 40 to 50 percent over capacity above peak demand (see table 4.2); a comfortable reserve margin is 20 to 25 percent above peak demand. Electrical demand in the province would have to grow by more than 3 percent per year to justify any further construction of nuclear plants before the turn of the century. The forecasts for demand by Hydro, however, have been consistently dropping (see table 4.3). Furthermore, the federal government contends that the demand for electricity will not increase over the next 30 to 40 years. EMR (1983) estimates a growth rate in electrical demand of only 0.2% per year until 2000, and negative growth in subsequent years.

With 14,000 MW of undeveloped hydro potential, and great opportunities in the field of industrial co-generation, Hydro could meet projected load growth well into the twenty-first century without building new nuclear stations. The risks and cost uncertainties associated with nuclear waste disposal and decommissioning would be diminished. Ontario Hydro, however, has remained firmly committed to its nuclear expansion program, and refuses to stop construction on nuclear plants, even in the case of Darlington where costs have already exceeded projections and the plant is only one-third complete (EMR, 1983). Hydro is concerned about not having an internal or external market for their surplus power and fearing adverse publicity and cost increases that might accompany a situation of large surplus capacity, the utility has embarked on a multi-million dollar "Go-Electric" public relations campaign, in an effort to raise the rate of growth in demand (EMR, 1983).

CHAPTER 6

SUMMARY AND CONCLUSIONS

This paper has attempted to analyze two major issues in the production of electricity from nuclear powered stations. The first issue concerns the aspect and costs associated with nuclear waste disposal and decommissiong of nuclear plants. The second is the obvious undervaluing by Ontario Hydro in estimating nuclear waste disposal and plant decommissioning costs.

Chapter 1 examined the total generation costs of nuclear and coal-fired plants. Even if one accepts the generating cost estimates in this paper it merely shows that nuclear power is the cheapest way to do something that is probably undesirable already, namely, to increase production of electricity, the most expensive form of energy in Ontario. The issues in question, however, are the unwanted risks and cost uncertainties of waste disposal and plant decommissioning that are associated with nuclear power.

Chapters 2 and 3 deal with these issues of nuclear waste disposal and plant decommissioning. Probably the most ignored aspect of nuclear power is what to do with nuclear plants once their design lives are over. The lack of experience with decommissioning costs, casts some doubts on the accuracy of cost estimates, but Ontario Hydro's estimates appear to be grossly underestimated.

The great public concern over nuclear waste disposal is demonstrated by the fact that no one is likely to want a nuclear waste disposal facility in his or her own backyard. The question which emerges is: does anyone have the right to force a community to live with dangerous wastes of a technology they did not choose and which, may not be needed for electrical uses? The problems involved with estimating waste disposal costs are immense since no final procedure has yet been decided upon, but again it appears that Hydro has underestimated the costs associated with waste disposal.

Plant decommissioning and nuclear waste disposal are clearly the "hidden costs" of nuclear power. Someone will have to pay for these costs, either electricity consumers now or in the future, or taxpayers. Since public utilities are most likely going to underestimate these costs of nuclear waste disposal and plant decommissioning, there will be a great burden on future generations to pay for these costs.

Chapter 4 examines the alternatives to the problems of nuclear waste disposal and plant decommissioning. Demand for electricity is the forgotten half of the economic comparison between nuclear and coal-fired plants. Growth rates have fallen sharply, and load forecasts are several points lower than they used to be in the past. It has been argued that it is cheaper to supply energy by renewable sources, small-scale hydro-electric plants, industrial co-generation techniques, and use of energy conservation measures, rather than by nuclear or coal means.

Although many aspects remain unsolved concerning the issues of nuclear waste disposal and plant decommissioning costs, this paper can be regarded as another step in addressing these issues. During the 1980's, the Canadian nuclear establishment should devote itself entirely to solving urgent problems of nuclear decommissioning and waste disposal. These problems will require solutions in any event, whether nuclear power has a future or not. Moreover, the techniques and equipment developed in Canada to solve such problems may be exportable at a profit to other countries facing similar problems.

A P P E N D I X A

APPENDIX A

A.1 COMPARATIVE COSTS OF NUCLEAR AND COAL WHICH AFFECT TOTAL PLANT GENERATING COSTS

1. *Total Cost = the capital cost plus operating and maintenance (O + M) costs plus fuel costs.

2. *Capital Cost = the sum of the direct and indirect costs that are needed to design, construct, and commission a project. This cost also includes financing charges. Direct costs include capital equipment and the actual physical plant.

   Indirect costs include engineering services and construction camps.

   +Financing charges are used by utilities to earn the necessary revenue to pay back investors, bondholders and stockholders for providing capital to finance construction. The revenue requirements are proportional to the plant's capital costs, corporate income taxes on net revenue, allowances for interim replacement of equipment and insurance. These costs are referred to as fixed charges and utilities calculate a fixed charge rate to get revenue requirements. Capital cost is expressed as dollars per kilowatt of installed capacity.

3. *Operating and Maintenance Costs = the costs of

labour and material required to maintain and operate a plant. Include such costs as operating labour, maintenance labour, maintenance materials, operating supplies and heavy-water upkeep and additional security for nuclear plants.

Operating and maintenance costs are expressed in dollars per kilowatt per year.

4. *Fuel Cost = the cost of ready fuel, uranium and coal over the generating station's design life. Expressed in dollars per kilowatt per hour of electricity produced.

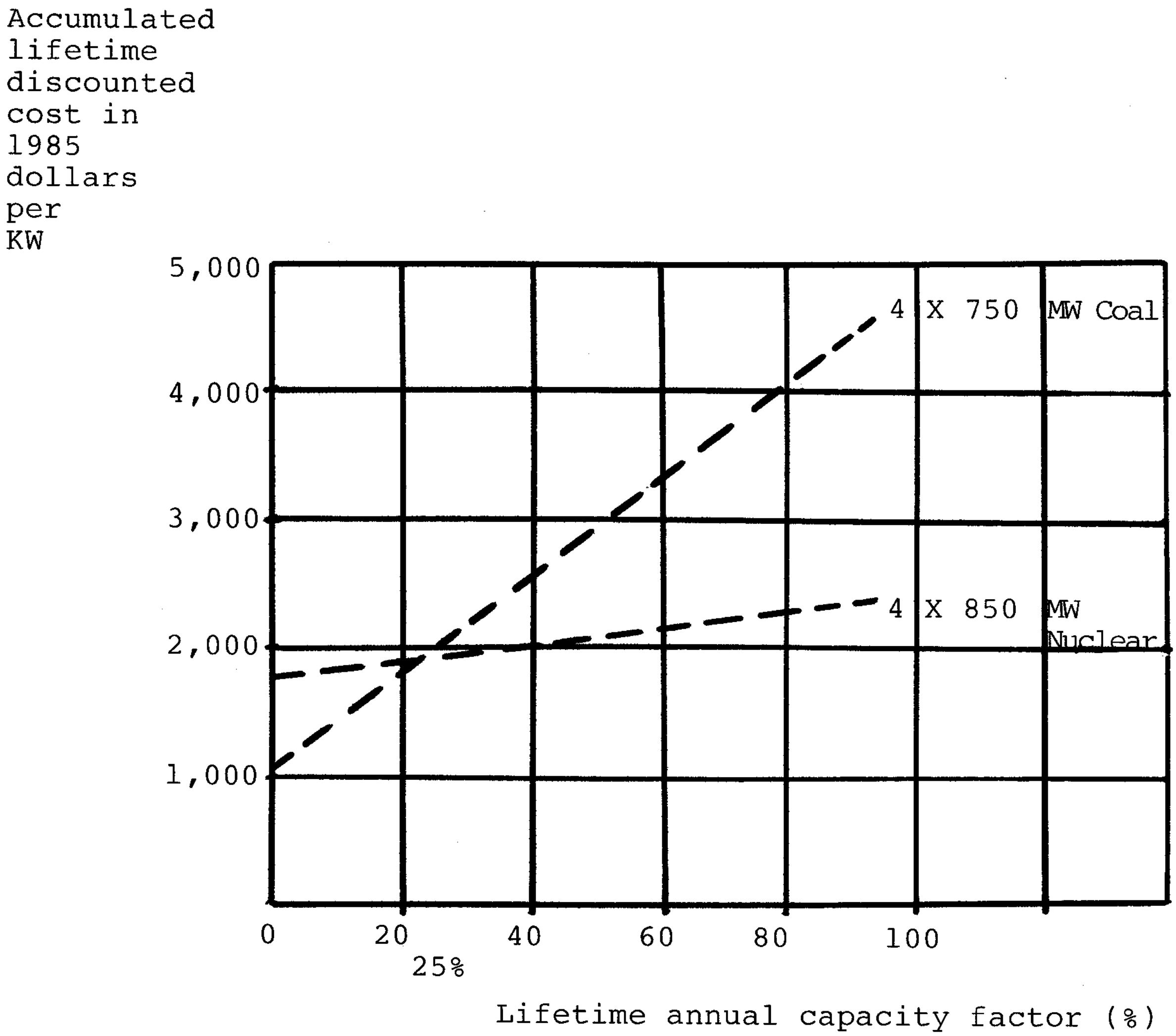
5. °Average Capacity Factor = an index of power plant performance. The ratio of the energy produced by a generating unit in a stated period of time to the theoretical maximum energy it could produce if it ran at its net capability 100% of that time.

*Canada, Royal Commission (1980)

°Rossin and Rieck (1978)

+Komanoff (1981)

FIGURE 1 ECONOMIC COST COMPARISON OF A NEW NUCLEAR AND A NEW COAL-FIRED GENERATING STATION COMING INTO SERVICE IN 1985



Sources

RCEPP and "Life-Cycle Costs of Coal and Nuclear Generating Stations", by J. Banerjee and L. Waverman, July 1978; a study commissioned by RCEPP.

TABLE 1.1 COMMONWEALTH EDISON'S LARGE GENERATING UNITS

Unit	In-Service Date	Net Capability (MWe)	Type	Construction Cost ($/kWe)
Coal				
Joliet 7	9 April 1965	537	Western	113
Joliet 8	21 March 1966	537	Western	113
Kincaid 1	7 June 1967	606	Illinois	118
Kincaid 2	10 June 1968	606	Illinois	118
Powerton 5	30 September 1972	850	Illinois	231
Powerton 6	19 December 1975	850	Illinois	218
Nuclear				
Dresden 2	11 August 1970	794	BWR	147
Dresden 3	30 October 1971	794	BWR	147
Quad Cities 1	16 August 1972	789	BWR	165
Quad Cities 2	24 October 1972	789	BWR	165
Zion 1	2 October 1973	1040	PWR	280
Zion 2	19 September 1974	1040	PWR	280

Source: Rossin and Rieck (1978)

TABLE 1.2 COMMONWEALTH EDISON'S 1977 BUS-BAR GENERATING COSTS

Cost(mills per kilowatt-hour of net generation)

Generating Unit Group	Fuel	Other Production, Operation, and Maintenance	Carrying Charges	Total
Nuclear				
System average	3.5	2.2	7.6	13.3
Six big units	3.5	2.1	7.5	13.1
Coal				
System average	12.1	3.0	9.0	24.1
Six big units	10.1	2.4	8.4	20.9
Powerton 5 & 6	7.7	2.1	11.5	21.3

Source: Rossin and Rieck (1978)

A P P E N D I X   B

TABLE 2.1 DECOMMISSIONING COSTS* IN COMPARISON TO THE CAPITAL COSTS OF PICKERING "A" AND BRUCE "A" NUCLEAR GENERATING STATIONS

	Pickering "A"	Bruce "A"
	(Millions of 1980 dollars)	
Original Capital Costs** (escalated costs)	1400	1900
Estimated Decommissioning Costs	162	196
Decommissiong As Percentage of Original Capital Costs	11.6%	10.3%

* deferring dismantlement by 30 years

** original capital costs exclude costs of heavy water and are expressed in escalated dollars to provide a meaningful comparison to estimated decommissioning costs.

Source: Ontario Hydro (1981)

TABLE 2.2 DECOMMISSIONING COST ESTIMATES

Source	Bardtenschlager Nuclear Engineering and Design 45 1985 U.S. $	Ontario Hydro Report 620 SP 1995 Can. $	General Public Utilities Corporation 1979 U.S. $	Unsworth Atomic Energy of Canada Limited 1979 Can. $
Type of Reactor	PWR	CANDU	-	CANDU
Size of Reactor (MW)	900 - 1300	4 X 850	906	600
Decommissioning Costs (millions)	80	8	101	30
Decommissioning Costs ($/kW)	120	2.4	125	-

TABLE 2.3 DECOMMISSIONING COST ESTIMATES

Source	Ontario Hydro Report 620 SP 1995 Can. $	U.S. Nuclear Regulatory Commission 1978 U.S. $	Komanoff Projected Cost, 1988 Plants (in 1979 Constant U.S. $) U.S. Average	N.E. Region	West Region
Type of Reactor	CANDU	PWR	PWR	PWR	PWR
Size of Reactor (MW)	4 X 850	1100	1150	1150	1150
Decommissioning Costs ($ millons)	8	45	-	-	-
Decommissioning Costs ($/kW)	2.4	40.9	138	172*	132

*decommissioning costs rise in the same proportion as nuclear capital costs which are higher for the Northeast region.

A P P E N D I X C

TABLE 3.1 STAGES AND WASTES IN THE NUCLEAR FUEL CYCLE

THE NUCLEAR CYCLE

	Process	Radioactive Waste
Front End	Uranium Mining	Waste rock (low-grade ore) Mine waters, (contain Ra-226 but are used in mill) Ventilation air (contains Rn-222)
	Milling	Mill Tailing Th-230, Ra-226, Rn-222 and sometimes Th-232 Waste water, mainly Ra-226 Ventilation air, mainly Rn-222
	Refining	Impurities from U, mainly Ra-226
	Conversion to oxide	Wastes are recycled
	Fuel Fabrication	
	Reactor Operation	Reactor Wastes
Back End / U and Pu	Irradiated Fuel If no Processing →	Irradiated fuel for storage and disposal
	Fuel Reprocessing	High level waste Actinide Waste for disposal

Source: (Aikin, 1980)

C.1 POTENTIAL HAZARD OF NUCLEAR WASTES

Actual hazard from toxic materials is more dependent on their availability to man rather than their degree of toxicity (Bruno, 1977). For example, lead is used in house plumbing, and mercury is used in dental fillings. The potential hazard is present but the actual hazard is small since these elements are in insoluable form. There is also potential hazard associated with radioactive wastes: gamma radiation, beta particles, and alpha particles. Gamma radiation is very penetrating and can pass through the body. It is hazardous whether the source of radiation is inside or outside the body. Beta particles can penetrate through the skin, but to a much lesser degree than gamma radiation. It is most hazardous when the source is ingested or inhaled (inside the body). Alpha particles cannot penetrate the body. Sources of alpha particles are hazardous only when ingested or inhaled.

The following examples can illustrate the concept of potential hazard. Cesium-137 emits both gamma radiation and beta particles. Thus, it is hazardous both to the outside and inside of the body. Strontium-90 emits only beta particles. It is mainly hazardous if inhaled or ingested. Plutonium-239 emits only alpha particles and it can be held in the hand without harm. Thus, it is only hazardous when inhaled or ingested.

Source: Boulton (1978)

A P P E N D I X D

TABLE 4.1 ENERGY R & D EXPENDITURES (in millions $)

Year	1976/ 1977	1977/ 1978	1978/ 1979	1979/ 1980	1980/ 1981	1981/ 1982
Total	120.5	118.2	150.7	157.9	173.9	205.9
Nuclear	90.3	87.9	105.8	106.4	117.2	118.4
% Nuclear	70	74	70	67	67	57.5

Source: EMR, Office of Energy R & D, Ottawa

TABLE 4.2 HYDRO OVER-CAPACITY ABOVE PEAK DEMAND (MW)

Year	1976	1977	1978	1979	1980	1981
Peak Capacity	19,677	21,347	22,845	24,429[a]	24,457[b]	24,595[c]
Peak Demand	15,896	15,677	15,722	16,365	16,808	16,600
Over-Capacity (%)	24%	36%	45%	49%	45%	48%

Source: Ontario Hydro Annual Reports(1982)

Note: a includes 550 MW moth-balled
b includes 1709 MW moth-balled
c includes 1913 MW moth-balled

TABLE 4.3 ONTARIO HYDRO PEAK LOAD GROWTH FORECASTS TO YEAR 2000 (per year) (percentage)

Year	19709-76	1977	1978	1979	1980	1981	1982
Forecast Rate	Over 7%	6.2%	5.3%	4.5%	3.4%	3.1%	3.0%

Source: Canada (1978); Ontario Hydro Annual Reports

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A C R O N Y M S

ACF	-	Average capacity factor
AECL	-	Atomic Energy of Canada Limited
BWR	-	Boiling water reactor
CANDU	-	Canada Deuterium Uranium
CCNR	-	Canadian Coalition for Nuclear Responsibility
EMR	-	Department of Energy, Mines, and Resources
IAEA	-	International Atomic Energy Agency
kg	-	kilogram
LWR	-	Light water reactor
kW.h	-	kilowatt hour
MW	-	Megawatt (one million watts)
O & M	-	Operation and maintenance
PWR	-	Pressurized light water reactor
RCEPP	-	Royal Commission on Electric Power Planning
R & D	-	Research and Development
U	-	Uranium