NUCLEAR vs COAL ELECTRICITY GENERATION IN CANADA

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Some parts of Canada are beginning to realize very significant benefits from nuclear electricity as compared to coal generation. In the province of Ontario alone nuclear electricity generation has displaced more than six billion dollars (Canadian) worth of coal imports. The associated cost savings to electricity consumers have amounted to more than two billion dollars. In addition, nuclear electricity is becoming an essential vehicle in Ontario Hydro's efforts to reduce the acid gas emissions from coal plants. In the next five years the increased use of nuclear electricity generation will allow 30% of fossil capacity to be mothballed and the load factor of coal plants to be reduced from 50% to 20%. Thus acid gas emissions will be reduced by 50% and Canadians will enjoy the additional benefits of a cleaner environment.

1. INTRODUCTION

This paper focusses on three technical issues related to the choice between nuclear and coal electricity generation : economics, environmental, and health. While there are of course other factors to be considered in the choice, such as security of supply, short term versus long foreign exchange requirements, etc., the technical issues are quantifiable and therefore more readily resolved.

In some parts of Canada, in particular, the technical issues of nuclear versus coal have received serious consideration. With respect to economics, the issue centers largely on the cost of coal. This paper therefore addresses two specific economic situations : a case where the coal plant is adjacent to the coal mine, and a case where the coal has to be imported from a distance of more than 800 km.

The environmental effects of nuclear and coal plants are not peculiar to any one country. The most significant environmental impact of coal generation is the emission of acid gases. This paper therefore presents the approach taken by one particular Canadian utility in reducing acid gas emissions, i. e. by substituting with nuclear generation.

The detrimental health effects of air pollutants due to coal fired plants are well known and undeniable. On the other hand the public risks from nuclear plants are minimal and diminishing further, as nuclear plants are becoming increasingly more

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註 : 本稿는 지난 10월 5일 개최된 美國原子力學會(ANS) 韓國支部 月例技術討論會에서 發表된 內容을 要約한 것임.

reliable and the risks from radioactive emissions increasingly smaller. The full impact of these facts has not yet been appreciated in the debate of nuclear versus coal. For this reason it is also briefly discussed in this paper.

2. ECONOMICS OF NUCLEAR AND COAL GENERATION

It is generally recognized that the economics of nuclear generation are largely governed by the initial capital cost, whereas the significant cost factor for coal is the fuel cost. Capital cost and interest are relatively independent of location. The cost of coal, on the other hand, is strongly influenced by distance of the plant from the coal mine.

In Canada two distinct situations present themselves :

Case 1 : Coal plant adjacent to a coal mine

Case 2 : Coal plant more than 800km from the mine

The coal costs for the two cases differ widely and are therefore of interest.

2.1 Case 1: Coal Plant Adjacent to Coal Mine Alberta, Canada

This case applies to the western Canadian Province of Alberta. A study carried out in 1982 (Reference 1) compared a CANDU nuclear plant with a similar sized coal plant. The parameters are given in **Table 2.1.1**. The results of this study are presented in terms of Levelized Unit Energy Cost (LUEC) in **Table 2.1.2**.

The results show quite clearly that a coal plant burning coal which costs only $12/tonne(1982 Canadian dollars) will have significantly lower LUEC (about 20% lower) than a comparable sized nuclear plant. Coal at $12/tonne is, however, available only from strip mining, requiring removal of only a few meters of overburden, and where transportation cost is essentially zero.

〈Table 2.1.1〉 Case 1 : Alberta, Canada

Parameters	Nuclear	Coal (+FGD)
Plant size (MWe Net)	2×600	3×375
Capital Cost (MS Cdn 1982)	1,780	942
In-service	1990	1990
Capacity Factor	80%	80%
Economic Lifetime (Yrs)	30	30
Delivered Fuel Cost	$175/kgU	$12/tonne
Fuel Escalation Rates	6.9%	8.5%
Real Discount Rate	6%	6%

〈Table 2.1.2〉 Case 1 Results LUEC

(1982 Cdn Mills/KWh)

	Nuclear	Coal
Capital	18.3	10.5
Operation+Maintenance	6.8	4.8
Fuel	5.1	9.4
Total	30.2	24.7

The case where coal has to be imported and transported over large distances is more common and of greater interest.

2.2 Case2 : Coal Plant More than 800Km from Coal Mine Ontario, Canada

Ontario Hydro is a provincially owned utility with installed generating capacity of 27,000MW (e). Peak power demand in 1984 was 18,900MW (e), and hydro, coal, and nuclear generation accounted for 34%, 32%, and 34%, respectively. (Nuclear generation in 1985 is expected to exceed 40% of total).

During the 1970's Ontario Hydro installed similar sized nuclear and coal plants. Each year the total unit energy costs from these plants are calculated, using identical calculation methods (Refe-

〈Table 2.2.1〉 Case 2 : Bruce 'A' vs Nanticoke

Station Data	Nuclear	Coal
Plant Size (MWe Net)	4×775	8×497
In-service	1977 – 1979	1973 – 1978
Capital Cost (M $ Cdn)	1, 961. 1	872. 9
Capacity Factor	93. 7%*	93. 7%
Economic Lifetime (Yrs)	40	35
Depreciation	Linear	Linear
Interest Rate (%)	12. 4	12. 4

*Actual 1984 Capacity Factor for four Bruce 'A' units

〈Table 2.2.2〉 Case 2 Results: Bruce 'A' vs Nanticoke TUEC in 1984

(Cdn Mills/KWh)

	Nuclear	Coal
I. D. D.	10. 61	3. 21
O. M. A.	3. 45	1. 55
Fuel	4. 40	25. 47
D20 Upkeep	0. 27	–
Total	18. 7	30. 2

*Includes Interest, Depreciation, and Decommissioning charges

rence 2). Thus very reliable cost comparisons now exist, and these are of direct interest to any utility operating both nuclear and coal plants within the same grid.

Two very pertinent comparisons can be made :

a) the Pickering 'A' N.G.S. (a 2, 000MW (e) CANDU nuclear station) vs the Lambton T. G.S. (a 2, 000MW (e) coal thermal station). Both plants went into service in the early 19 70's

b) the Bruce 'A' N. G. S. (a 3, 200MW (e) CANDU nuclear station) vs the Nanticoke T. G. S. (a 4, 000MW (e) coal thermal station).

Both comparisons give very similar results. For sake of brevity only the details of the Bruce 'A' vs Nanticoke case are presented here. The parameters characterizing these two stations are given in **Table 2. 2. 1.** The results of the comparison are presented in **Table 2. 2. 2.**

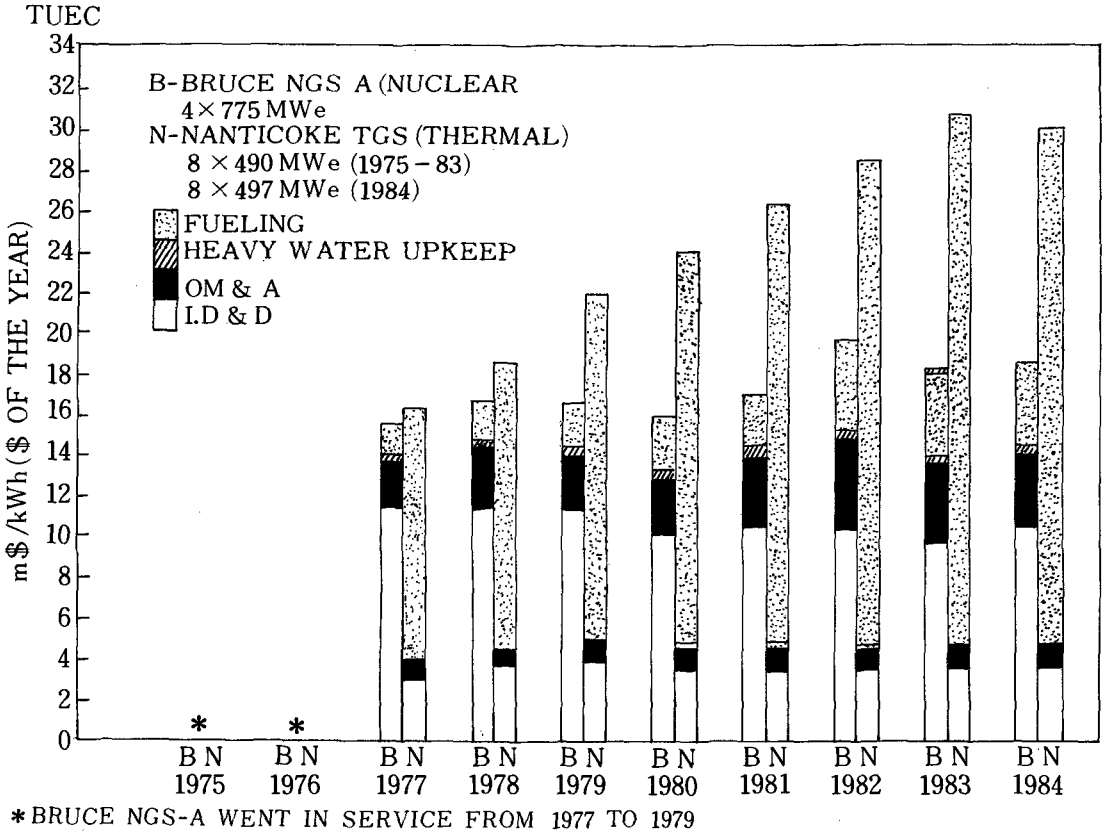
The results show quite clearly that for base load operation with high capacity factors the nuclear electricity from Bruce 'A' will be of the order of 30 to 40% less expensive than coal generation from Nanticoke. In fact, in most years the coal fuel cost alone exceeds the total generation cost from the nuclear plant. The comparisons for the years 1977 to 1984 are shown in **Figure 2. 2. 1.** It can be seen that the costs of electricity from the two stations were comparable only in the first two years of operation. Thereafter, the nuclear electricity has been consistently and very significantly less expensive than the electricity from coal.

It should be appreciated that the advantage of nuclear generation is directly related to its annual capacity (or load) factor. During 1984 the four Bruce 'A' CANDU units operated with an average capacity factor of 93. 7%. Since the fuel cost of both nuclear and coal plants is directly related to their load factors, Whereas the other cost components in **Table 2. 2. 2.** are largely independent of load factor, simple calculations show that the nuclear electricity from Bruce 'A' would remain less expensive even at load factors as low as 45%.

2. 3 Cumulative Cost Savings 1971 – 1984

As a result of the outstanding operation of Ontario Hydro's CANDU nuclear plants more than 6 billion dollars (Canadian) worth of coal purchases have been displaced since the early 1970's. Most of this coal would have had to be imported. Thus, valuable foreign exchange was conserved. In addition, the cumulative savings to Ontario electr-

〈Figure 2.2.1〉 Total Unit Energy Cost Components Thermal Versus Nuclear (1975–1984)



*BRUCE NGS-A WENT IN SERVICE FROM 1977 TO 1979

icity consumers, to the end of 1984, amounted to 2.1 billion dollars. By 1990 the annual savings alone will be of the order of 1 billion dollars.

3. ENVIRONMENTAL EFFECTS

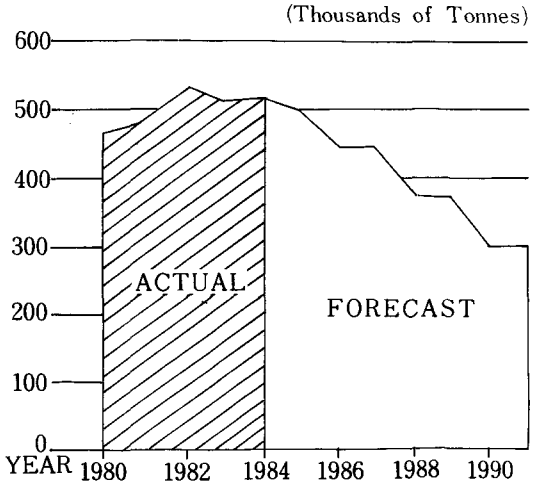
World-wide the choice between nuclear and coal plants is beginning to be increasingly influenced by environmental considerations. It is well known that nuclear generation is environmentally clean. Coal-plants, on the other hand, emit enormous quantities of particulates, sulfur dioxide, nitrogen oxides, carbon dioxide, trace metals (including thorium, uranium, etc.), and other pollutants. Even when coal plants are fitted with flue gas scrubbers and other pollution control equipment they still emit large quantities of acid gases and pollutants into the air. Such equipment merely reduces the emissions but does not eliminate them.

3.1 Acid Gas Emissions from Coal Plants

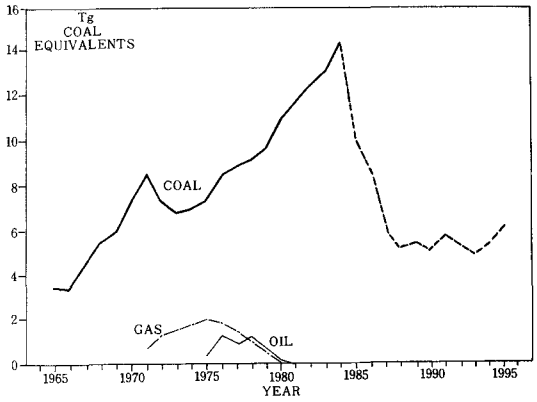
Of the various pollutants, the acid gases, SO_2 and NO_X, have recently created considerable concern. Although it is recognized that there may be other factors as well, acid rain, formed from the acid gases emitted by coal plants, is believed to be contributing to the deterioration of large areas of forests and lakes in many industrial countries. As a result, some countries have already introduced specific regulations aimed at curbing the emission of acid gases from coal plants.

To control acid rain, the federal and provincial governments in eastern Canada have established a guideline deposition level of less than 20kg / ha /

〈Figure 3. 1. 1〉 Acid Gas Emissions



〈Figure 3. 1. 2〉 Fossil Fuel Consumption



yr of wet sulphate. The emissions from Ontario Hydro's coal plants contribute about 20% of the province's total (Reference 3). To assist in reducing these acid gas emissions Ontario Hydro and the Ontario Ministry of the Environment agreed in 1981 to limit SO_2 and NO_x emissions from Ontario Hydro's coal plants. Subsequent regulations enacted by the Ontario Government set specific limits for the total and SO_2 emissions, such that Ontario Hydro's emissions will be reduced by about 50% by 1990.

Acid gas emissions will be reduced via :

a) reduction in coal sulphur content (which means burning more expensive coal)

b) installing flue gas control technology

c) displacing coal generation with more nuclear generation

The forecast annual emissions of acid gases, when all three of the above methods are applied, are shown in **Figure 3. 1. 1.** The corresponding decrease in coal consumption may be seen in **Figure 3. 1. 2.**

The reduction in acid gas emissions so as to meet Ontario Government regulations will ultimately lead to 30% of Ontario Hydro's installed fossil capacity being mothballed, and the annual load factor of coal plants will have to be reduced from about 50% in 1985 to 20% in 1990. The corresponding reduction in electricity generation from coal will be met by increasing the share of nuclear generation.

3. 2 Environmental Effects of Nuclear Plants

Nuclear plants cause no air pollution and give rise to only minor amounts of chemical effluents. The only emissions from nuclear plants are small amounts of radioactivity, which are quite negligible compared with the radioactive background due to natural radiations. The environmental effect, or, more specifically the effect on the quality of air and water, due to the operation of nuclear power plants is therefore generally accepted to be insignificant.

The only notable environmental effect due to nuclear generation lies in certain aspects of uranium mining. As the quantities of uranium that are mined and processed are, however, extremely small by comparison with coal, the relative environmental effects of nuclear qeneration are indeed insignificant compared to those of coal.

〈Table 4.0.1〉 Excess Deaths vs SO_2 Concentrations

Date	Place	SO2 Level (ppm)	Excess Deaths
Dec.1952	London	1.5	3,900
Dec.1962	London	1.0	850
Jan. 1956	London	0.51	1,000
Nov.1966	New York	0.51	168
Nov.1952	New York	0.2	360
Jan. 1959	London	0.2	200
Dec.1962	Osaka	0.1	60

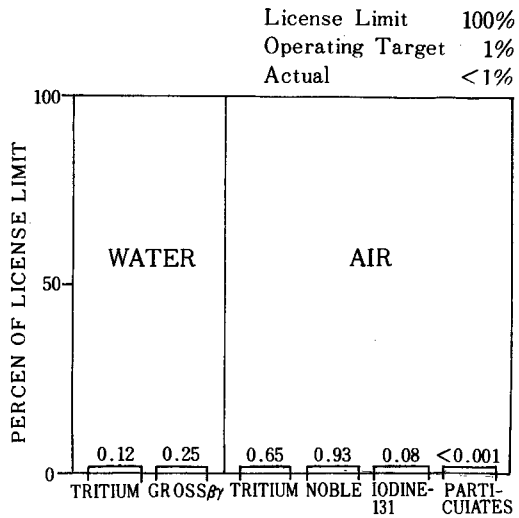
4. THE HEALTH EFFECTS OF NUCLEAR AND COAL GENERATION

The detrimental health effects of air pollutants due to coal burning are real and undeniable. During the 1950's and 1960's significant increases in deaths attributable to air pollution occurred in several major cities throughout the world. **Table 4.0.1.** shows the number of excess deaths in some of those cities correlated with measured concentrations of SO_2 in the air (Reference 4). The excess deaths were attributed to bronchial complications caused by the small particulates emitted in coal burning (the SO_2 level is merely an indicator of air pollution, and not the cause of the excess deaths).

While the severe conditions of the 1950's and 1960's are now less frequent, large numbers of excess deaths are still attributed to the burning of coal. In North America alone the median number of premature deaths correlated with coal burning is still estimated to be 50,000 per year (Reference 5).

In contrast, there exist no observed public health effects that could be correlated with nuclear power generation. The only observable health effects related to nuclear power are those experienced by uranium miners. Compared to the health effects of coal mining, however, the total risk due to uranium mining is considerably smaller (Reference 6).

〈Figure 4.0.1〉 Radioactive Emissions 1984 (Bruce NGS-A)



To appreciate fully the very low public health risks from the operation of nuclear plants one need only to compare the additional radioactive doses received by persons living close to nuclear power plants to the doses from natural radiations received by all human beings on earth. To be specific, residents in the vicinity of a CANDU nuclear plant are estimated to receive less than one milli-rem of additional radioactive dose annually. (Actual radioactive emissions from the Bruce 'A' station for 1984 are shown in **Figure 4.0.1**, where the actual emissions correspond to a dose of 5 milli-rem/year to the most exposed member of the public). By comparison, the average annual dose from natural sources of radiation received by all humans is of the order of 100 milli-rem. This is an average world-wide. The actual doses vary widely with location, and range up to thousands of milli-rem in some locations on the surface of the earth. Thus, an additional dose of the order of

〈Table 4.0.2〉 Excess Deaths Per Year Due to Electricity Generation with 1,000MWe Nuclear and Coal Plants*

Occupational	Excess Deaths/Year Nuclear Plant	Coal Plant
Mining and Fuel Handling	0.4	2
Transportation	–	2.4
Electricity Production	0.1	0.1
Public		
Mining and Fuel Handling	–	5
Transportation	–	0.5
Electricity Production (Emissions)	<0.1	50
Totals	<0.6	60

*Values shown are averages of the ranges quoted in Reference 6 and assume 70% load factor for both nuclear and coal-plants

one milli-rem or less from the operation of nuclear plants is considered to present an extremely low additional health risk indeed.

Public concern often focusses on the risks due to accidental emissions of radioactivity. A detailed discussion of this topic is beyond the scope of this paper. Nevertheless, a summary comparison of all risks related to yearly electricity production from 1,000MW(e) nuclear and coal plants is given in **Table 4.0.2** (Reference 6). The public risks shown for "electricity production" from the nuclear plant (i.e. much less than 0.1 excess deaths per year, possibly zero) are in fact dominated by the "routine radioactive emissions." The risks from accidental releases are much smaller because of their low frequency, and due to the effective retention of the various radioactive nuclides during accident conditions.

In contrast to these low public risks from nuclear generation, the public health effects of coal generation are at least two orders of magnitude larger. This fact can not be overlooked in the choice between nuclear and coal.

5. SUMMARY

In some parts of Canada, such as Ontario, the choice between nuclear and coal is clear : the economics, environmental, and public health effects all favour nuclear. It is recognized that the economics of coal depend largely on the price of coal, which in turn depends on location. Nuclear can not compete with coal when the coal plant is adjacent to a coal mine. However, nuclear electricity can be significantly less expensive than coal when the latter has to be imported and transported over great distances.

The detrimental environmental and public health effects of coal burning are undeniable. Nuclear electricity, on the other hand, is clean and safe. Based on these considerations alone the author believes that the choice for any utility should be nuclear.

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