AECL-5689

ATOMIC ENERGY OF CANADA LIMITED

L'ÉNERGIE ATOMIQUE DU CANADA LIMITÉE

UTILIZATION OF WASTE HEAT FROM ELECTRICITY GENERATING STATIONS

by

R.F.S. ROBERTSON

Whiteshell Nuclear Research Establishment

Pinawa, Manitoba

June 1977

ATOMIC ENERGY OF CANADA LIMITED

UTILIZATION OF WASTE HEAT FROM ELECTRICITY GENERATING STATIONS

by

R.F.S. Robertson*
Director of Special Projects
Atomic Energy of Canada Limited
Whiteshell Nuclear Research Establishment
Pinawa, Manitoba

Nuclear waste heat may save fossil fuels, a shorter version of this article, appeared in Modern Power and Engineering, 70(7): 46-49 (1976).

Whiteshell Nuclear Research Establishment

Pinawa, Manitoba

June, 1977

*Present address: Department of Energy, Mines and Resources, Ottawa, Ontario.

AECL-5689

Utilisation de la chaleur résiduelle des centrales électriques

par

R.F.S. Robertson
Ministère de l'Energie, des Mines et des Ressources
Ottawa, Ontario

Résumé

Historiquement, la centrale nucléaire a été conçue seulement pour produire de l'électricité. Mais au Canada, aujourd'hui, seulement 15% de notre consommation énergétique se présente sous forme d'électricité. Les besoins non-électriques de notre époque sont satisfaits presque entièrement par le gaz naturel et le pétrole. Il serait bon de déterminer si une centrale nucléaire pourrait fournir de l'énergie pour quelques-uns des besoins non-électriques, ce qui permettrait d'employer le gaz et le pétrole à des usages pour lesquels ils seraient plus valables et appropriés, particulièrement dans les transports. Un groupe situé à l'Etablissement de Recherches Nucléaires de Whiteshell a entrepris une série d'études pour examiner ce problème. Ces études ont été assez poussées pour donner des réponses technologiques et économiques et par conséquent, plusieurs rapports ont été publiés sur diverses questions. Dans le présent rapport, les résultats de ces études sont regroupés dans une évaluation du potential d'emploi de la chaleur résiduelle au Canada.

L'Energie Atomique du Canada, Limitée
Etablissement de Recherches Nucléaires de Whiteshell
Pinawa, Manitoba, ROE 1LO

Juin 1977

AECL-5689

Nuclear waste heat may save fossil fuels, une version abrégée de cet article, a été publiée dans Modern Power and Engineering, 70(7): 46-49 (1976).

UTILIZATION OF WASTE HEAT FROM ELECTRICITY GENERATING STATIONS

R.F.S. Robertson
Department of Energy, Mines and Resources
Ottawa, Ontario.

ABSTRACT

Historically the nuclear power station has been designed solely as an electricity producer. But in Canada today only 15 percent of our energy consumption is as electricity. The non-electrical needs today are supplied almost entirely by natural gas and oil. There is an incentive to see whether a nuclear station could supply energy for some of these non-electrical needs, thus freeing gas and oil for uses for which they may be more valuable and suitable, especially in transportation. A group located at the Whiteshell Nuclear Research Establishment undertook a series of studies to examine this problem. These studies were done in sufficient depth to provide technological and economic answers, and as a result several reports have been published on various topics. In this report, the findings from these studies are drawn together in an assessment of the potential in Canada for using waste heat.

Whiteshell Nuclear Research Establishment
Pinawa, Manitoba ROE 1LO
June, 1977

AECL-5689

Nuclear waste heat may save fossil fuels, a shorter version of this article, appeared in Modern Power and Engineering, 70(7): 46-49 (1976).

CONTENTS

1. INTRODUCTION

We are now well aware that, for the short term at least, our supplies of oil and natural gas are limited, that these commodities are becoming ever more expensive, and that we are and will be, probably for the rest of this century, net importers of oil. The self-reliance policies outlined in the recent document, "An Energy Strategy for Canada", (1) suggest a 1985 target of reducing net imports to one-third of our total oil demands.

Historically the nuclear power station has been designed solely as an electricity producer. But in Canada today only 15 percent of our energy consumption is as electricity. The remainder is distributed as follows:

SECONDARY ENERGY CONSUMPTION IN CANADA
(Adapted from (2))

Electrical	15%
Non-Electrical	
Space Heating	25%
Industry	30%
Transportation	24%
Other	6%

The non-electrical needs today are supplied almost entirely by natural gas and oil. There is an incentive to see whether a nuclear station could supply energy for some of these non-electrical needs, thus freeing gas and oil for uses for which they may be more valuable and suitable, especially in transportation.

A group located at the Whiteshell Nuclear Research Establishment undertook a series of studies to examine this problem. These studies were done in sufficient depth to provide technological and economic answers, and as a result several reports (3-10) have been published on various topics. In this report the findings from these studies will be drawn together in an assessment of the potential in Canada for using waste heat.

2. STEAM CYCLES

Waste heat is usually defined as that heat which is rejected during the electrical generation process at a very low temperature (10-25°C) in a form which is difficult and expensive to use. However, it is possible to reject this heat at a much higher, more usable temperature. Such a process would lead to a lower production of electricity but it would lead to a much better utilization of the heat content of the initial fuel.

The efficiency of the cycle is determined by the temperature at which the steam is raised and the temperature at which it is condensed. The efficiency is given by: Efficiency = $(T_{Hot} - T_{Cold})/T_{Hot}$, where T_{Hot} and T_{Cold} are the generating and condensing temperatures. Typically, a CANDU generating station operates at an efficiency of 30 percent, while fossil fuel stations operate at a generally higher efficiency - about 35-40 percent. In today's electrical generating stations, certainly in North America, and in general throughout the world, to achieve the best efficiency, the low temperature, T_{Cold}, is kept as low as possible. Thus, although over two-thirds of the heat generated in the boiler is rejected in the cooling water, it is rejected at a very low temperature. Typically, the cooling water comes into the condenser at 10°C (50°F) and leaves it at 23°C (74°F). This is very low grade heat - truly waste - and it is hard to find a suitable use for it. One attractive application will be discussed later but, in general, it is difficult to heat anything with a heat source at only 23°C.

The foregoing is only one way in which energy can be extracted from a turbine steam cycle. To produce both heat and electricity some of the steam can be diverted either before it reaches the turbine or at some stage within the turbine itself. The net result of course is that for the same total heat generation the electricity production will be less. However, the steam (or hot water) which is diverted can be used at nearly 100 percent efficiency and hence the overall fuel utilization is increased. Table 1 gives some illustrative numbers, and typical applications will be found in later sections. Such methods are usually referred to as steam extraction, or intermediate condensing cycles. This type of usage is especially attractive where the heat load is needed for only a period of time. When the heat is not needed, extra steam is available for electricity production.

Still another method of operation is feasible. The steam from the turbine need not be condensed at 23°C - it can be condensed at any temperature desired. However, it should be noted that the higher the condensation temperature required, the less work the steam can do. If heat above 100°C is required, the steam must be condensed at a higher pressure.

Because the condensing temperature is increased, the electrical production efficiency is lowered. However, the resulting heat can be used at high efficiency, and Table 1 shows that the overall energy utilization is high.

Back pressure turbines are found in industrial applications where large amounts of heat but small amounts of electricity are required. They are of more use in a base heat load application where heat is needed continuously but they are not so attractive for, say, a district heating system which requires heat for only a fraction of the year.

In summary, the dual production of heat and electricity from a central generating station leads to a more efficient utilization of primary fuel than does electricity production alone. Hence there is an incentive to install these dual-purpose stations. The remainder of this article examines the question of whether the economic incentive is as strong as the technical incentive outlined above.

3. HEAT UTILIZATION

Puttagunta (8) has found that, of the energy consumed as heat in Canada, only 9 percent is required at a temperature above 260°C. His distribution for heat energy consumed is:

Above 260°C	9%
140-260°C	14.5%
100-140°C	26.5%
Below 100°C	50.1%

Above 100°C the heat is required mainly for industrial purposes while that below 100°C is used in space heating.

This presentation will consider three principal temperature regimes: that in the range 260-110°C involving higher grade heat whose usage is mainly in the industrial sector; that in the range 110-60°C where the application is mainly for space heating using lower grade heat; and the regime below 60°C where the application of this low grade heat appears to be principally in the fields of agriculture or aquaculture.

3.1 HIGHER GRADE HEAT IN INDUSTRY (260°C-110°C)

As noted earlier, roughly 30 percent of Canadian secondary energy consumption is by industry. Virtually none is provided from a large-scale central source but is generated by individual industries according to their needs.

An important fact from a survey of energy needs in industry in Canada (7) is the striking mismatch between the energy requirements for even a large industrial or commercial project and the energy available from a CANDU reactor. For instance, the energy needs of a large refinery with a throughput of 23,850 Mg (150,000 barrels)* per day are in the order of 800-900 MW thermal. This could be easily supplied by only one of the four reactors at the Pickering station used in a dual role as electricity and heat producer, and the electrical output would only drop from 514 to about 240 MW(e). Most industrial loads are even smaller - e.g. 70 MW typically for the pulp and paper industry, or 116 MW(t) for an ammonia plant.

To utilize properly the dual potentials of large centrally located generating stations, be they nuclear or fossil fuelled, either

*1 bbl = 159ℓ ≅ 0.159 Mg bitumen at 1 kg/ℓ (10° API gravity) (9).
≅ 0.139 Mg synthetic crude at 875 g/ℓ (30° API gravity).

very large concentrations of energy users are necessary, or energy must be transmitted over long distances. In Canada these large concentrations do not exist and industrial plants are so scattered that transmission of thermal energy is too expensive for the scheme to be practical. Indeed, a future trend for Canada may well be for industries to move and centralize in the vicinity of these large stations.

The question naturally arises, "Instead of building very large generating stations, why not build much smaller ones which are adapted to industries' needs?". Of course, with fossil fuels, this is what has been done historically. With the large escalation of oil and gas prices, the nuclear generating station has been studied to see whether it could fill this role. The problem is economics in that the technology required to build small stations is no different from that for large units but, as with other large engineering entities, unit costs rise sharply as the size decreases. Current licensing rules put such stringent demands on control systems, safety systems, inspection, etc. that only large sizes are economically competitive.

However, in Canada today there is one example of a utility supplying both heat, in the form of steam and electricity, to an industrial complex. The heavy water production industry requires large amounts of energy both as electricity and as process heat. On the site of the Bruce Nuclear Power Development in Ontario there is a plant producing nominally 800 tonnes of heavy water per year. This plant requires 70 MW of electricity and 600 MW as process steam (6). The thermal power is being provided as process steam from the 200 MWe Douglas Point reactor, backed up by three oil-fired boilers. Two new heavy water production plants are now being built, and the process steam will come from the nuclear reactors of the Bruce Generating Station which will start coming on-line during the latter part of 1976. Thus heavy water production at Bruce alone will utilize 210 MW(e) and 1800 MW thermal. In a similar manner, future heavy water production plants will, if possible, be located close to nuclear generating stations to take advantage of the availability of low cost steam.

One interesting application for which there is a huge market if the resource is developed to its full potential is the extraction and upgrading of bitumen from deep lying beds of the Alberta Tar Sands. Currently envisaged "in-situ" methods involve injecting steam into the bed to lower the bitumen viscosity so that it can be pumped or forced to the surface. A study has shown that the cost of nuclear steam is competitive with steam raised by burning coal as long as the delivered price of the coal is over $1.00/GJ ($17 per ton) (9).

3.2 SPACE HEATING (about 100°C)

Historically in Canada, because of cheap and abundant supplies of gas and oil, homes and buildings have been, in the main, individually heated rather than taking their heat from a centrally located supply. A few district heating systems were started earlier in the century but very few survive today.

However, increasing costs and decreasing availability of gas and oil have changed this picture. Already, electric heating appears competitive and many people are using it or seriously contemplate its use. A study has been completed by R.O. Sochaski and R.B. Lyon (5) to examine the economic position of nuclear heat. They considered bringing 600 MW of heat, as hot water, from a site such as Pickering, a distance of 40 km from the load centre. A previous study, which was done for the city of Toronto (10), had examined the possible integration and expansion of an established network of customers, and provided an excellent focus for this study. It was first established that the heat would be much more economically transported to the load by hot water rather than by steam. Several options were considered but the most important were:

(i) A dedicated 600 MW nuclear reactor having no turbine and supplying only hot water.

(ii) Supply of the 600 MW heat load from a reactor such as one of the Pickering reactors and accept the loss in electrical generation (Figure 1).

The cost of generating and distributing the heat by these two methods was calculated, and was compared with the cost of electrical heating in Toronto. Costs were escalated to 1980 and were compared to the cost of electric heating forecast to that time.

Table 2 summarizes the results obtained. The important conclusions are:

(i) A station which provides only heat shows highest efficiency in fuel utilization but suffers from a low load factor (0.35 percent) and hence total unit energy costs are higher because the station is not needed in the summer.

(ii) A dual-purpose station shows the expected increase in efficiency of primary energy utilization, and because heat not needed during the summer can be used to generate extra electricity for which there is always a demand, the cost of heat is significantly lower than that from the station producing only thermal energy.

(iii) The cost of distributing the heat at the load centre can be very high. In Table 2 the lower number is an estimate if the heat has to be distributed to only a few large loads, while the higher number represents the costs which would arise from distributing the heat to a housing development.

Thus the cost of generating the hot water was small compared to its transportation and distribution. The same would be true for a coal-fired station, and for a city such as Toronto where electrical rates are low, electrical heating could be as attractive to the customer as hot water supplied from a distance of 40 km.

A new study has just been published (11) in which the authors assess the technical and economic viability of a proposed scheme in which 8 MW of heat as hot water would be extracted from the Pickering B nuclear generating station (due for completion in the early 1980s) and piped a distance of 8 km to heat the proposed housing development of North Pickering, which is forecast to have a population of 70,000 by 1992. The heat would be produced during off-peak hours and stored for subsequent use. It must be emphasized that this is only a study and represents no commitments. The study concludes that the equivalent of 270,000 Mg (2 million barrels) of oil can be saved per year if the heat came from this scheme rather than from individual furnaces. Nuclear based district heating for this case would have high initial capital costs, mainly because of the transport distance and because of the storage needs, but in 14-18 years, depending on the price of money, nuclear heat would become cheaper than that from individual furnaces.

Both these studies suggest that for new towns located close to a generating station, district heating could be an interesting proposition. For small loads, coal or oil-fired installations will undoubtedly supply the initial heat but, as load increases, dual-purpose systems producing electricity and heat will come in. The major problems are political and sociological which obviously need evaluation.

3.3 LOW GRADE HEAT (below 60°C)

The great majority of the low grade heat produced today is in the form of turbine condenser cooling water, typically in the range 10-30°C. The quantity available will continue to increase and many methods of taking advantage of the large amount of energy contained in the warm water are being actually considered today. This section will discuss possibilities in aquaculture and agriculture.

There is one stream of cooling water from a CANDU reactor which has no parallel, either in other types of nuclear reactors or in fossil-fired stations. The fuel channels in the reactor are surrounded by the heavy water moderator. The purpose of this moderator is to slow the fission neutrons to low enough velocities that they can cause further fissions. This moderator absorbs about 7 percent of the fission energy and in a Pickering reactor, for example, roughly 120 MW of thermal energy is captured in the 260 metric tonnes of heavy water moderator. The optimum operating temperature of the moderator is 70°C, and hence a cooling circuit must remove heat continuously to maintain this temperature. Today, the cooling circuit is sized to reject this heat at a low temperature (max 36°C) but there is no inherent reason why the cooling circuit cannot be designed to reject the heat at a higher temperature.

3.3.1 Greenhouse Heating

At WNRE an application has been studied by Iverson et al (4) whereby a water stream from the moderator cooling circuit at 54°C is used to heat greenhouses.

This study considered a block of 10 hectares (25 acres) of greenhouses of modern design and we compared the cost of heating them by conventional oil- or gas-fired units circulating hot air, with the cost of circulating water at 55°C which is heated by a heat exchanger in the moderator cooling circuits. The capital costs were:

CAPITAL COSTS

(excluding cost of greenhouse or land)
10 hectares (25 acres) of greenhouses
35 MW max heat load

	Warm Water Heat (Moderator Heat Source	Hot Air Fossil-fired)
Reactor Modifications	$1,200,000	
Ventilation and Heat Distribution Pumps, Piping, etc.	$3,900,000	$1,555,000
	$5,100,000	$1,555,000
$/kW	146	44

Thus the capital cost of the warm water system is over three times that of the fossil-heated system. It can also be seen that the cost of modifying the moderator circuit is only one-third the cost of installing the necessary pipes, pumps, etc. to carry the hot water around the greenhouses.

However, having modified the moderator circuit, the heat is, in principle, free, and the major cost is recovery of the capital spent in converting the moderator system and installing the piping. If the greenhouses are heated by the conventional method of circulating hot air from an oil- or gas-fired furnace, the cost of fuel is the major item. Indeed, the rapidly escalating costs of gas and oil are a cause for grave concern in the greenhouse industry in Canada today.

The results of the study are summarized in Figure 2 which shows costs for the system described above, both for moderator heat and for conventional fossil-fired heat. Costs for the two systems (including capital repayment) will break even at fossil fuel cost of about $1.37 per gigajoule ($1.30 per million Btu). This corresponds to a cost of 23¢ per gallon of oil, or $1.30 per thousand cubic feet of gas delivered to the site. Today in Ontario the cost of non-interruptible gas supply is about $1.85 per thousand cubic feet. Thus such a system would be competitive today. Furthermore, Figure 2 shows that certain improvements which are identified in the report, and are all feasible in the short term, will lower the cost of heavy water by 20 percent.

A station such as Pickering could service well over 4 times this load - i.e. 40 hectares (100 acres) of greenhouses. In 1972 just over 120 hectares (300 acres) of greenhouses in Canada produced tomatoes and cucumbers valued at $13 million. The difficulties with this concept are that, in relation to the Canadian economy, the greenhouse industry will not require a large fraction of the waste heat which will be available. Furthermore, to make use of this cheap heat source, the members of the greenhouse industry would have to be prepared to move their greenhouses from their present locations and cluster them in the vicinity of one of the large nuclear generating stations. The study did not address itself to the social problems involved in such a change but obviously they would play a major role in determining whether or not this became a viable alternative.

3.3.2 Aquaculture

Short-term Potential - A study of aquaculture, in collaboration with members of the Freshwater Institute, has been completed which considers the use of condenser cooling water from a CANDU station for intensive aquaculture of rainbow trout, a species for which there is a ready market in Canada and which has been intensively studied in this country (3).

The study examined a facility using the condenser cooling water from a 600 MW(e) CANDU station. To raise 340 tonnes of rainbow trout per year to market size, a flow of only 0.6 cubic metres per second of condenser cooling water from an available discharge of 25 cubic metres per second is required. This would be accomplished in 40 concrete raceways, each 15.5 m x 2.5 m, with an average depth of 1.5 m. The temperature of the condenser cooling water supply would vary from 14°C in the winter to as high as 30-35°C, and the lethal limit is 24°C. Thus, during winter, full condenser coolant could be used, but during the summer as the temperature rose, the fraction of condenser cooling water would decrease. In certain locations, cool water from an aquifer or from deep in the lake might be necessary to keep the temperature below 24°C.

This operation calls for a stocking density of 0.22 kg of fish, per litre of water. Aeration will be necessary to sustain this high density, which roughly is an order of magnitude greater than stocking densities achieved in fish farms today. This high density has been demonstrated in the laboratory but not in the field, and thus field trials will play an important role in the demonstration of economic viability.

The capital cost of such a facility was calculated to be $684,000 and, assuming that this was amortized over 10 years at 10 percent per year (capital charge rate 0.1627), the annual costs were:

	$	$/kg fish
Capital charges	111,414	0.33
Labour and supervision	200,000	0.59
Utilities	61,000	0.18
Chemicals	5,000	0.02
Fish Food	251,000	0.75
Fingerlings for stock	75,000	0.22
Maintenance	50,000	0.15
Marketing	20,000	0.06
	773,414	$2.29

Today in Winnipeg, rainbow trout can be sold to the wholesale market for over $3.00/kg. In the above estimate, there is some doubt about the capital cost. However, if it were 3 times as high, the cost of fish would still be below $3.00/kg.

Today the annual import of rainbow trout into Canada is roughly 1000 tonnes. The above facility, which uses only 1/40 of the cooling water from a 600 MW(e) station, could supply 1/3 of this amount.

Long-Term Potential - Obviously, supplying rainbow trout for the Canadian market will require an insignificant fraction of the waste heat available. However, looking to the future, the supply of cheap protein is going to be of vital concern to the entire world. This protein can be available for human consumption. Intensive fish farming using waste heat shows exciting possibilities for supplying this protein but for it to become a reality the cost must be far below those quoted above. Some approaches are obvious.

Looking at the breakdown of costs shown above, the three major factors are payment of capital charges, the cost of fish food, and the cost of labour. As larger sized units come into operation, economics of scale would bring the unit capital cost down. Automation of fish rearing processes is obviously another goal. A significant reduction in the cost of feeding the fish is also necessary.

A way of diminishing food costs significantly could be by raising algae to feed the fish, and by using fish wastes as nutrients for algae growth, the food cycle could be closed. This may not be as far in the future as might be imagined.

Today in Calgary, the Sam Livingston fish hatchery raises 100 tonnes annually of trout fingerlings for Alberta's restocking program. This hatchery is unique in North America in two ways - it is totally enclosed, and, more importantly, it does not use a once-through supply of river water but recirculates the water, using only 10 percent make-up. To maintain the necessary water purity, biological filters of crushed rock and oyster shells and conventional clarifiers are used. Thus today a method to remove and retrieve fish wastes from the water is available.

There are several projects today demonstrating the culture of algae by various wastes. One which is in the pilot plant stage is operated by Dr. L. Boersma at Oregon State University (12). Thus the component parts of a potential process are available now. It is to be hoped that someone will put them together before too long.

4. CONCLUSIONS

The studies described in this paper show that a nuclear generating station, designed to produce heat and electricity can utilize primary fuel more efficiently than one designed for electricity alone. In addition, nuclear heat can, in many instances, supplant heat from burning natural gas or oil. The potential for space heat alone is large when it is considered that for a town of only 70,000 people, 270 Gg (2 million barrels) of oil per year may be saved.

However, the major problem is that the heat load should be in the proximity of the generating stations - preferably less than a few kilometres. For loads farther away, costs of transporting the heat will outweigh any advantages gained from lower generation costs.

There are no major technical barriers to the provision and distribution of heat from a central nuclear source. However, the sociological implications need to be examined, especially if economic usage depends on close proximity.

Whether or not the ideas incorporated in this report come to fruition will depend very much on our energy resource utilization in the future. If frontier oil and gas prove to be more plentiful than now anticipated, or if production of liquid fuel and synthetic natural gas from coal or the Alberta Tar Sands proceeds more quickly to a cheaper product, then the needs and economics for dual production of heat and electricity may not be apparent. If none of these eventualities come about, the more efficient use of primary energy resources may be the overriding consideration towards implementation of central heat and electricity supplies.

Finally, very low grade waste heat will always be difficult and expensive to use as a heat source. However, its utilization as a source of warm water to promote animal or vegetable growth will play an important role in securing food supplies for the future.

5. REFERENCES

1. An Energy Strategy for Canada Department of Energy Mines and Resources, Ottawa, Canada (1976).

2. An Energy Policy for Canada, Phase 1 - Vol. I & II. Department of Energy Mines and Resources, Ottawa, Canada (1973).

3. J. E. Guthrie, D. R. Prowse, Dr. D. P. Scott, Nuclear Power Plant Waste Heat Utilization for Freshwater Fish Farming, Atomic Energy of Canada Limited, Report AECL-4924 (1975).

4. S. L. Iverson, D. R. Prowse, Dr. J. D. Campbell, An Assessment of the Utilization of Waste Heat in Greenhouses, Atomic Energy of Canada Limited, Report AECL-5109 (1976).

5. R. B. Lyon, R. O. Sochaski, Nuclear Power for District Heating, Atomic Energy of Canada Limited, Report AECL-5117 (1975).

6. R. F. S. Robertson, The Supply of Steam from CANDU Reactors for Heavy Water Production, Atomic Energy of Canada Limited, Report AECL-5118 (1975).

7. R. F. S. Robertson (Editor), The Application of Nuclear Energy to the Canadian Chemical Process Industry, Atomic Energy of Canada Limited, Report AECL-5232 (1976).

8. V. R. Puttagunta, Temperature Distribution of the Energy Consumed as Heat in Canada, Atomic Energy of Canada Limited, Report AECL-5235 (1975).

9. R. O. Sochaski, V. R. Puttagaunta, R. F. S. Robertson, The Potential of Nuclear Energy in the Recovery of Oil from the Alberta Tar Sands, Atomic Energy of Canada Limited, Report AECL-5239 (1976).

10. Technical Report of the Steering Committee of the City of Toronto District Heating Study - James F. Maclaren Limited, City Departments and Toronto Hydro, December 1973.

11. D. Anderson and R. L. Gudgion, Ministry of Energy District Heating Study. A report prepared for the Ontario Ministry of Energy by Acres Shawinigan Limited, Toronto, Ontario (1976).

12. L. Boersma, E. W. R. Barlow, J. R. Miner and H. K. Phinney, Annual Waste Conversion Systems Based on Thermal Discharges, Special Report 416, Agriculture Experimental Station, Oregon State University, Corvallis, Oregon, September 1974.

TABLE 1

COMPARISON OF TURBINE TYPES

	CONVENTIONAL	EXTRACTION TURBINE	BACK PRESSURE TURBINE
	All Power Units Expressed as Megawatts		
Thermal Heat Generated	1000	1000	1000
Station Losses	50	50	50
Electricity Generated	285	186	83
Electrical Transmission Loss	29	19	8
Electricity to Customer	256	167	75
Heat Used	-	330	867
Temperature Heat Used (°C)	-	250	190
Heat Transmission Losses	-	33	87
Heat to Customer	-	300	780
Heat Wasted to Cooling Water	665	431	-
Energy Utilization Efficiency $\left(\frac{\text{Heat + Electricity to Customer}}{\text{Thermal Heat Generated}}\right)$	25.6	46.7	85.5

TABLE 2

DISTRICT HEATING COST COMPARISONS

600 MW THERMAL HEAT LOAD

	THERMAL ONLY	DUAL THERMAL ELECTRIC	ELECTRIC RESISTANCE HEATING (SYSTEM DATA)
Reactor Core (MWt)	706	2200	-
Energy Utilization (%)	85	37	27
Load Factor %	35	80	68
UNIT THERMAL ENERGY COSTS (m$/kW·h)			
Station	9	5	
Pipeline (40 km)	8	8	
Distribution	3-24	3-24	
Total	20-41	16-37	30

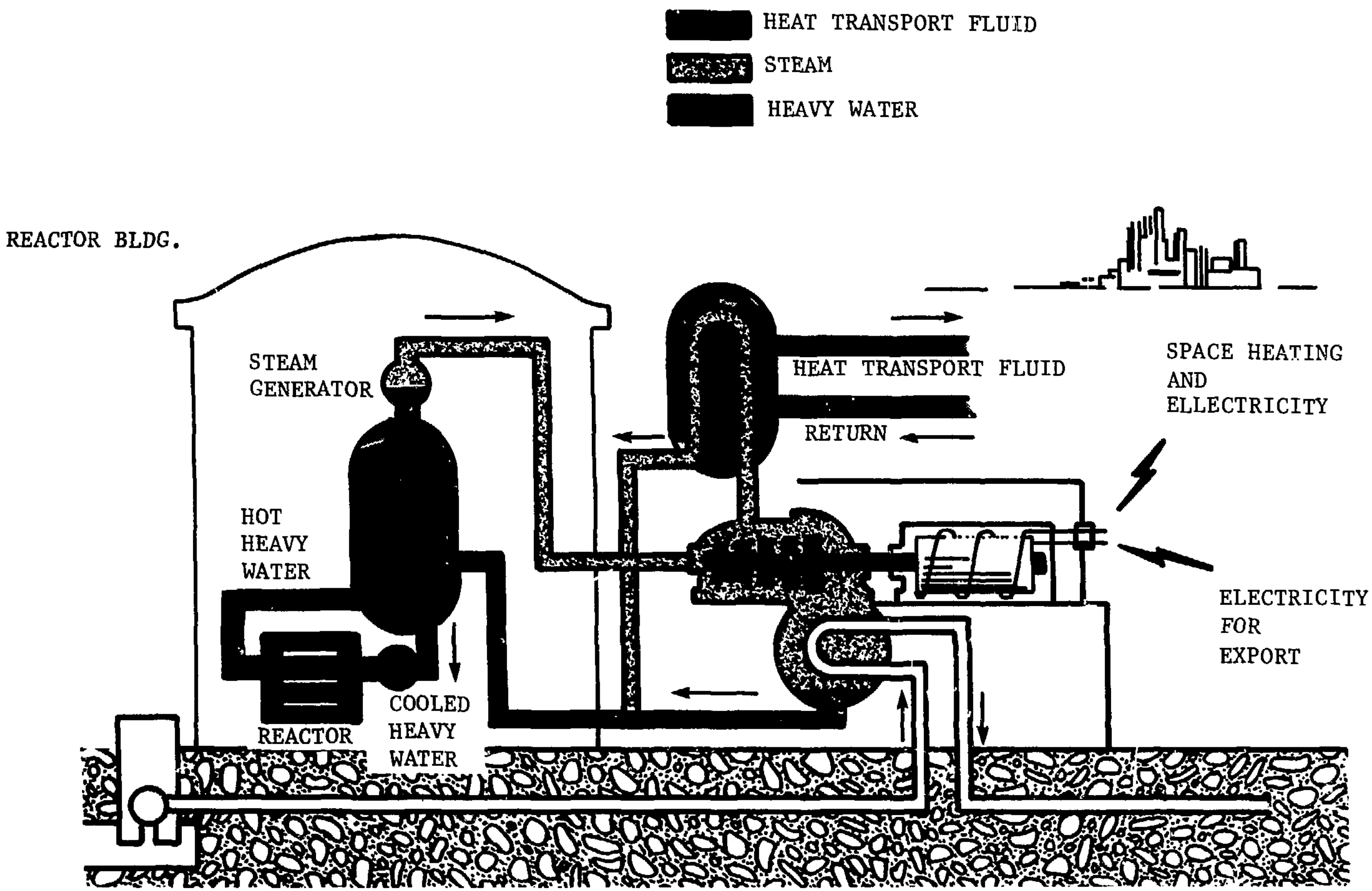

FIGURE 1. THERMAL/ELECTRIC STATION

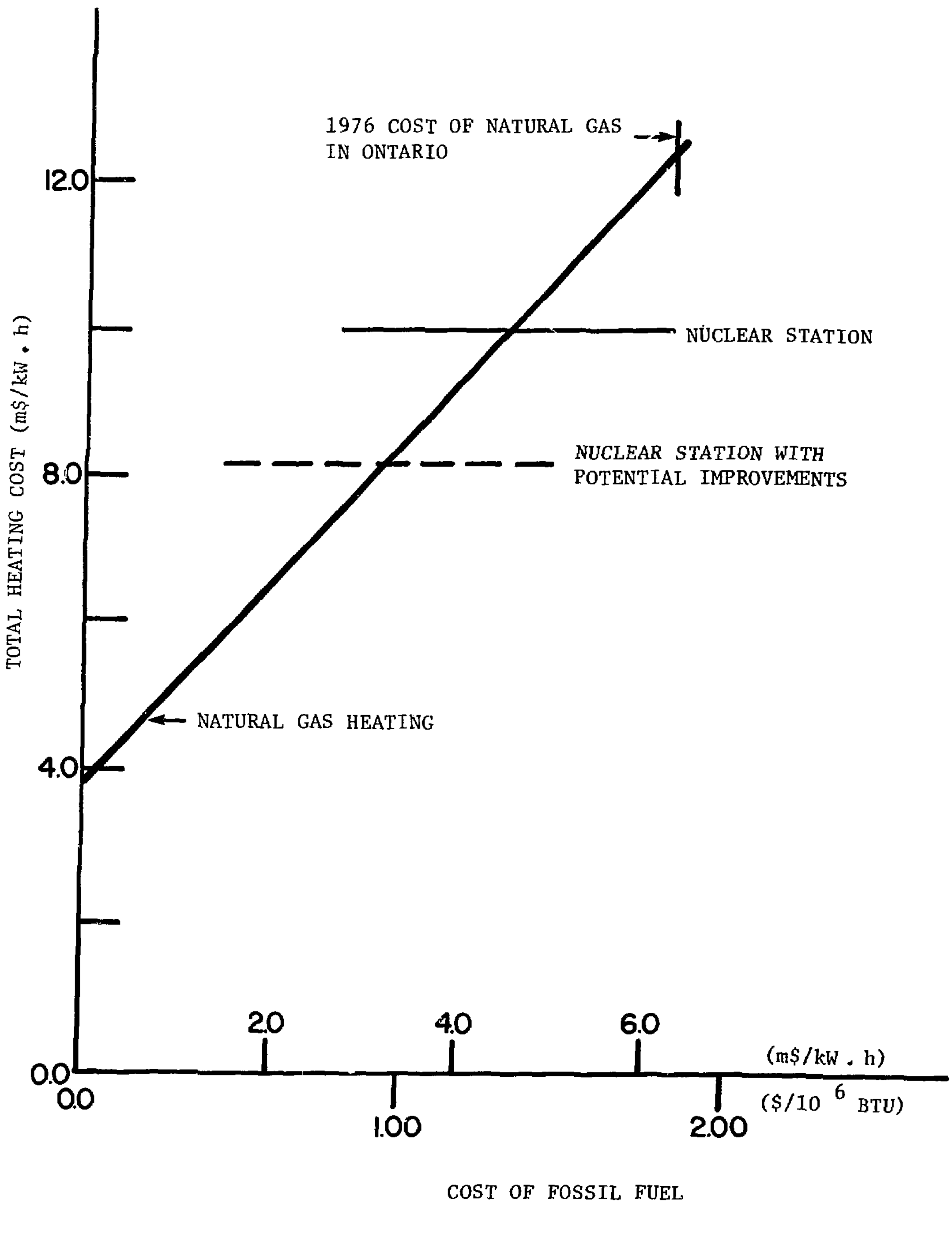

FIGURE 2. COMPARISON OF NUCLEAR AND NATURAL GAS HEATING COSTS FOR GREENHOUSES IN ONTARIO

The International Standard Serial Number

ISSN 0067–0367

has been assigned to this series of reports.

To identify individual documents in the series
we have assigned an AECL–number.

Please refer to the AECL–number when
requesting additional copies of this document
from

Scientific Document Distribution Office
Atomic Energy of Canada Limited
Chalk River, Ontario, Canada
K0J 1J0

Price $3.00 per copy

1106-77