# SASKATCHEWAN POWER CORPORATION
# FEASIBILITY STUDY
# FOR A
# NUCLEAR POWER PROGRAM
# IN SASKATCHEWAN

Prepared By

SASKMONT ENGINEERING COMPANY LIMITED
Regina, Saskatchewan
May 1973

SASKMONT ENGINEERING COMPANY LIMITED
CONSULTING ENGINEERS

306-525-0561
TELEX 031-2721

810-1867 HAMILTON STREET
REGINA, SASKATCHEWAN

30 May 1973

Mr. E.R. Smith
Chief Engineer, Electrical System
Saskatchewan Power Corporation
Scarth Street and Victoria Avenue
Regina, Saskatchewan

Saskatchewan Power Corporation
Nuclear Program Study
SEL 3208-6 NP 000

Dear Mr. Smith;

We submit herewith our report on the Feasibility Study for a Nuclear Power Program for Saskatchewan, prepared in accordance with the Terms of Reference and authorization contained in your letter of February 22, 1973.

The report contains preliminary estimates of capital and operating costs and resulting energy costs for a nuclear power station comprising 2 - 600 MW units located in Saskatchewan.

In addition, the report describes the development of nuclear power in Canada and the effects of a nuclear power program on both the Province of Saskatchewan and the Saskatchewan Power Corporation.

We shall be pleased to review the report with you, and to provide any additional information which you may require.

Yours very truly,

G.M. Pearson, P. Eng.
President
Per:

Z. Kolisnyk

CAA

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Report by Canatom Ltd.

"Saskatchewan Power Corporation
Nuclear Power Plant Study"

# 1.0 INTRODUCTION

# 1.0 INTRODUCTION

## 1.1 TERMS OF REFERENCE

The Saskatchewan Power Corporation engaged Saskmont Engineering Company Limited to carry out a feasibility study for a possible nuclear power program in Saskatchewan. The authorization was given by Saskatchewan Power Corporation in their letter dated February 22, 1973.

The terms of reference for the study were as follows:

1. Description of reactor types.
2. Special aspects related to the following -
    - Cost
    - Fuelling
    - Thermal Discharge
    - Load Fluctuation
    - Staffing
    - Safety
    - Radioactive Discharges
3. Design description of the CANDU reactor.
4. Safety controls in Canada.
5. Environmental aspects of nuclear power.
6. Radiation effects.
7. Nuclear development in Canada.
8. Future prospects for nuclear power.
9. Effects of nuclear power in Saskatchewan.
10. Costs of nuclear power including capital and operating costs.

## 1.2 ACKNOWLEDGEMENTS

Several sections of the report which follows have used the information and contents of the report of April 1972 entitled "Provincial Power Study, Section 10, The Status of Nuclear Power in Canada" by Montreal Engineering Company, Limited for the British Columbia Energy Board.

Canatom Ltd. was engaged to perform a specific study for locating a nuclear power plant in Saskatchewan and their report entitled "Saskatchewan Power Corporation, Nuclear Power Plant Study" is included in this report as part of Section 7.

# 2.0 SUMMARY AND RECOMMENDATIONS

## 2.0 SUMMARY AND RECOMMENDATIONS

A nuclear power plant comprising an initial 600 MW unit with provision for a second 600 MW unit in a central location in the Province was considered for the feasibility of undertaking a nuclear power program in Saskatchewan. The selection of a 600 MW unit was dictated by the benefits of a modern plant containing proven components of the size to attain maximum economy and reliability of nuclear power generation. A smaller unit of 200 MW - 300 MW capacity, although feasible, would not generate power at competitive costs.

Although the energy costs for a plant of the type described in the report appear attractive, they are not based on firm power, and accordingly, the cost of reserve capacity must be added. Alternatively, the provincial grid should be large enough to absorb a 600 MW unit without affecting the system reliability and reserve.

With a probable load forecast of 6%/year peak load growth, the Saskatchewan system would be able to support a 600 MW unit with the reliability of 11% reserve capacity only in the late 1990's. If a higher load forecast of 10%/year peak load growth were assumed, the earliest the system could support such a unit would not be until the late 1980's.

Accordingly, depending on the actual load growth in the Province during the next decade, it will not be until the late 1980's or 1990's that a nuclear power program could be an attractive choice for Saskatchewan.

The costs of nuclear power in the report reflect a high load factor over the entire life of the plant. The result of displacing other generating plants in the provincial system to lower load factors, and the effects on the system have not been examined.

Although no specific site has been considered for the nuclear station, the estimates have been based on a site located adjacent to a large body of water such as Diefenbaker Lake to dispose of the thermal discharges from the condenser cooling water system.

The schedule for the first 600 MW unit is estimated to be 72 months from the date of approval and a construction work force peak of 600 - 800 men is envisaged.

The report describes two alternative methods of contracting for the installation of a nuclear unit, namely, one in which the owner participates in the design, construction and construction management, and the other where the owner engages outside consultants to carry out these activities. AECL would design the reactor in both cases.

The report also describes the requirement of specialized trained staff for the operation and maintenance of nuclear power plants. A number of operating personnel with special skills would have to be trained over a period of 5 to 6 years prior to entering into a nuclear power program, with a continuing on-the-job training program after the first station is operational. A limited nuclear power program of the type described would have limited effect on the Corporation's head office staffing, since only a small group would be needed for coordination and assistance to management, and legal and safety aspects of the operation of the plant.

# 3.0 GENERAL

## 3.0 GENERAL

### 3.1 REACTOR TYPES

A nuclear power station is identical in concept to a fossil fuel-fired (coal, oil, gas) power station except that a nuclear reactor takes the place of the boiler. The steam from the NSSS (Nuclear Steam Supply System) drives a conventional steam turbine; and, as in the case of the conventional plant, the thermodynamic cycle requires the condensing of turbine exhaust steam with consequent dissipation of heat. Hence, the station must have a source of cooling water such as a river, lake or ocean, or be equipped with cooling towers.

In the countries which have developed nuclear power to date, four types of reactor predominate as proven power reactors for central generating station usage. Other reactors exist but must still be classified as research reactors.

The two systems of power reactors developed in the U.S.A. are cooled and moderated with ordinary water, sometimes called light water to distinguish them from the heavy water systems. They are referred to as the PWR and BWR systems.

The PWR or pressurized water reactor was originally developed for power by the Westinghouse Company, but it is now built by other suppliers in the U.S.A., and under license or independently in other countries. There are more stations under contract for the PWR system than any other.

The BWR or boiling water reactor is primarily associated with the General Electric Company, but is also built for power under license outside of the U.S.A.

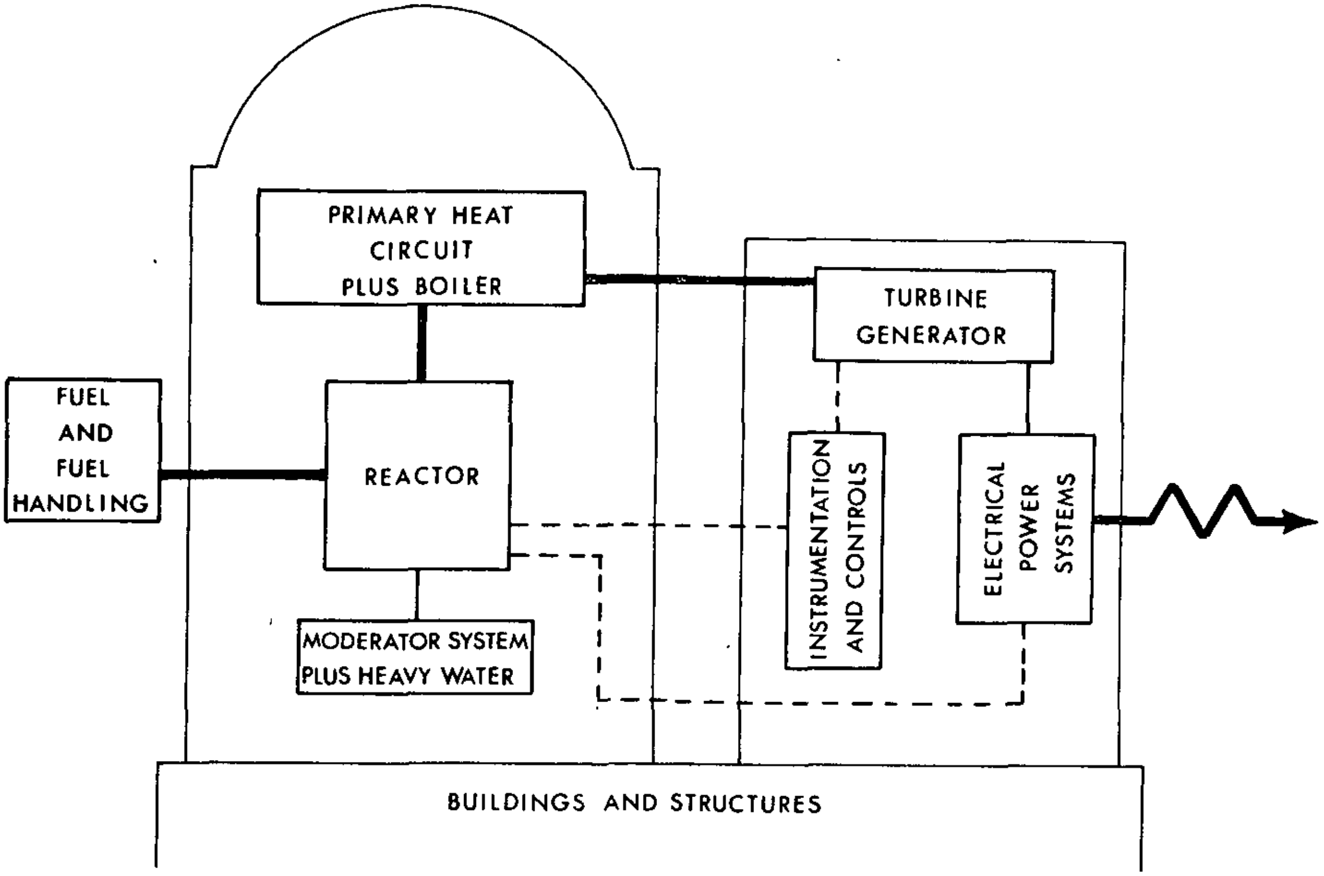
The GCR or gas-cooled reactor was developed for power initially in Britain and France. It uses a graphite core with compressed carbon dioxide gas as the heat exchange medium. Recently, some sales of a high temperature GCR have been made (by Gulf General Atomic) in the U.S.A. Helium is used as the heat exchange medium in the high temperature gas cooled reactor known as HTGR. The 40 MW(e) Peach Bottom HTGR prototype was considered to be a success and is reported to have the highest net thermal efficiency of any nuclear plant in service. The Fort St. Vrain Plant at Platteville, Colorado is a 330 MW(e) HTGR unit and was commissioned in 1972.

The HWR or heavy water reactor has been adopted for power by Canada. It can be designed either on an indirect cycle or direct cycle system. Only the former, known as the PHWR (pressurized heavy water reactor), has achieved commercial status. Canada and Britain have both built experimental prototype versions of the direct cycle, viz., Canada (BLW) and Britain (SGHWR), but none has been built commercially as yet. The Canadian power reactors, both PHW and BLW, are known as CANDU reactors, the acronym being derived from Canadian-Deuterium-Uranium. They are of the calandria type in which heavy water is the moderator and a coolant is circulated past fuel bundles located in coolant pressure tubes. With the sole exception of the CANDU reactor which is fuelled with natural uranium, all current commercially available power reactors use enriched uranium, the market supply of which is dominated by the U.S.A. Although the USSR has supplied small quantities, and Britain and France have small production plants, it is the United States Atomic Energy Commission (USAEC) which provides the great bulk of the world's supply and which dictates the market price.

CANDU power reactors have an operating cost lower than that of any other reactor type, and lower than fossil fuel-fired stations in most parts of the world. Moreover, the hardware, or reactor component of a CANDU power station is no more expensive than that of any other nuclear station; but the heavy water adds about 20 percent to the capital cost of the plant. Hence, the capital investment in Canadian nuclear plant is higher than in other types. In the past decade, high interest charges have not favoured plants with high first cost, and this is the main reason why the CANDU has not been successful in the export market. Potential customers have also been disturbed by the uncertainty of heavy water supply, a situation which has only recently begun to be rectified. However, the success of the first two Pickering reactors, which were commissioned during 1971 with remarkably few start-up problems, may influence world opinion in favour of the CANDU system especially as it comes at a time when there is growing unease about the long-term availability and price of enriched uranium.

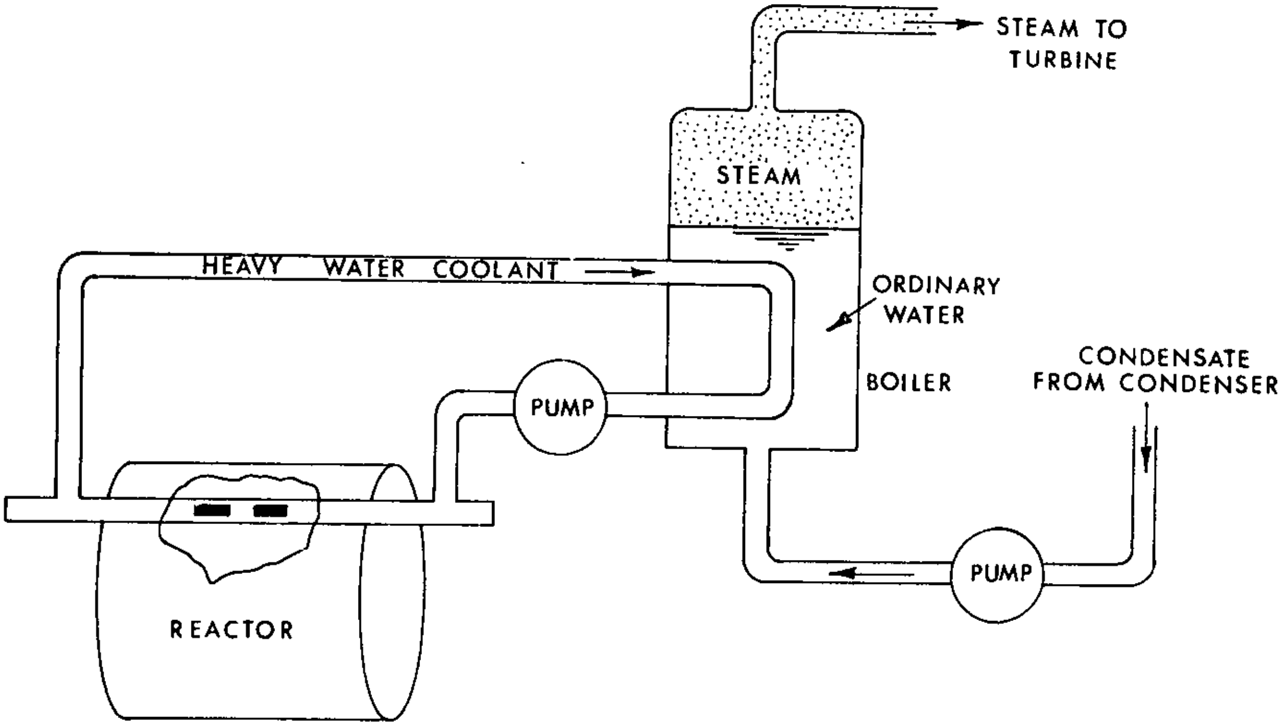
Figure 3-1 shows the main components of a nuclear power system in a simple block diagram.

Figure 3-2 is a pictorial representation of the steam generation processes by CANDU PHW and CANDU BLW reactors.

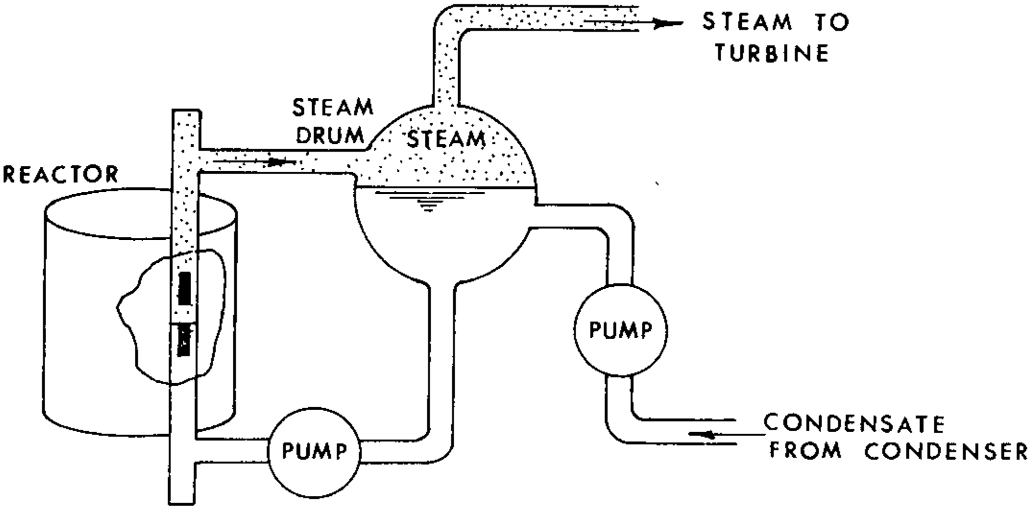


MAIN COMPONENTS OF A NUCLEAR POWER STATION

FIGURE 3-1



CANDU (PHW) PRESSURIZED HEAVY WATER
REACTOR STEAM GENERATION PROCESS



CANDU (BLW) BOILING LIGHT WATER
REACTOR STEAM GENERATION PROCESS

FIGURE 3-2

## 3.2 SPECIAL ASPECTS OF NUCLEAR POWER

The principal ways in which nuclear power generation differs from other forms of power generation are as follows:

### 3.2.1 Cost

Nuclear power is a high capital cost, low running cost means of energy production. This is particularly true of the Canadian reactor. A CANDU power station may cost twice as much as an alternative conventional thermal plant. However, it has a fuelling cost of about 1 mill/kwh, which is lower than most Canadian fossil fuel costs. Hence, once the station is built, it tends to be less sensitive to inflation relative to other fuels. Moreover, there is no technical development to undercut its running cost, which can be foreseen; and it can therefore be assumed to remain in base-load service throughout its life. This is not true of the U.S. light-water reactors with their higher (enriched) fuel cost, some of which have already been downgraded to two-shift operation.

It should also be noted that a utility installing nuclear power for the first time incurs higher first costs than a utility making an incremental addition to existing nuclear plant. These higher initial costs are for staff training and the provision of certain ancillary services.

### 3.2.2 Fuelling

A 500 MW coal-fired station may consume 4,000 tons of bituminous coal or 8,000 tons of lignite coal a day. A 500 MW CANDU plant consumes a truck load of uranium fuel every month, and requires no rail sidings, mechanical handling plant, ash disposal or other ancillaries. Fuel deliveries would be made a few times a year. Spent fuel is stored in open pools within the station. It contains plutonium, a material which is expected to have a considerable market value in a few years' time as a fuel for fast breeder reactors. It is therefore expected that after a few years, the spent fuel elements will be removed and sold. Present policy is to build a storage pond large enough to hold the elements discarded in ten full-power years of operation.

The economics of a nuclear plant are affected in a negligible way by its location relative to the source of fuel.

### 3.2.3 Thermal Discharge

Because of the lower operating temperature of a reactor compared with a fossil fuel fired boiler, the Carnot cycle efficiency of the prime mover is lower, and about 60 percent more heat is rejected to the cooling water than from an equivalent conventional thermal plant. This question is discussed further in Section 3.4.

### 3.2.4 Load Fluctuation

The latest CANDU-PHW station design can tolerate large load variations. Load can be accepted at a more rapid rate than normally considered for conventional thermal stations, and it can be rejected instantaneously with the turbines throttling back to supply station service only. However, if the plant drops load after having been operating at full power for several days of more, a phenomenon known as xenon poisoning will occur and cause a shutdown unless reactor loading can be restored to about 65 percent of full power within 30 minutes. To avoid such an occurrence, a turbine bypass is now provided in CANDU-PHW plants to permit raising reactor power within the specified time limit and bypassing the excess steam to the main condenser where it raises the temperature of the cooling water discharge.

This problem does not occur with enriched fuel reactors which operate with higher excess reactivity levels.

### 3.2.5 Staffing

A nuclear power station is more complex than a conventional thermal power station and requires a larger staff for operation and maintenance. Moreover, a larger number of the staff require specialized training; and for some of them, this training must begin as soon as the station is committed. Preferably, a candidate for such training is a man with good conventional thermal power station operating experience.

All operators of CANDU stations to date, including those in Quebec and overseas, have been trained in Ontario Hydro's school associated with the NPD (nuclear power demonstration) reactor at Rolphton, Ontario.

Staffing with special reference to Saskatchewan Power Corporation is discussed in Section 6.3.

### 3.2.6 Safety

The reactor core contains a large quantity of highly toxic material; and it is the responsibility of safety authorities to assure that there is no risk of this material escaping accidentally. They have obviously discharged their responsibilities well, because no member of the public has ever been injured or affected in any measurable way by the operation of a commercial nuclear power station anywhere in the world. This subject is dealt with in Section 3.3.

### 3.2.7 Pollution

It is possible to design a reactor with zero discharge of radioactive gases or liquids, but such a design would be excessively expensive. Hence, to date a reasonable economic compromise has been sought. As a result, fluids containing radioactivity much below the level of measurable damage to life or the environment are today discharged to the air or to the cooling water. In recent months, the opposition to nuclear power has argued that all radioactivity is bad, in any quantity. Most scientists, however, refuse to accept that radioactivity at levels below that found in nature (cosmic rays, granite, etc.) to which mankind has been subjected for millenia can possibly be harmful. This subject is further discussed in Section 3.4.

## 3.3 SAFETY ASPECTS OF NUCLEAR POWER

### 3.3.1 Safety Control Under Normal Operating Conditions

Nuclear power carries with it certain potential hazards to the community, but in countries where these aspects have been exhaustively studied, it has been concluded that the hazards are acceptable. There are significant differences of approach to the problem of safety in the leading nuclear nations, but the general intent of the rules and regulations that have been evolved is common; that is, the exposure to radiation by plant staff and the public must not exceed specific limits. These have been established by the national nuclear plant licensing authorities in all countries in which nuclear power is being developed.

They usually contain a large factor of safety to ensure that an acceptable degree of risk is not exceeded. The International Commission for Radioactive Protection (ICRP) has established standards for allowable concentrations of radioactive isotopes in air and drinking water.

Allowable releases of radioactive liquids and gases from a reactor system can be derived from accepted calculation methods which take account of the indirect routes by which radioactive substances can be transmitted to the general public. For example, allowable levels of radioactive liquid effluent can be derived by considering the external type of radioactive substance transmitted to the public due to concentration in the sea food chain. The radioactive discharge from the plant may be concentrated in algae which are consumed by fish, and which in turn are ultimately consumed by humans. It is a relatively simple matter to determine the degree of concentration in the food chain which is thus likely to occur, and then by working backwards to set a limit to the allowable continuous discharge of radioactive material from the plant. However, while this problem has been extensively studied, there are as yet no internationally agreed standards for an acceptable level of radioactivity transmitted by these indirect routes.

### 3.3.2 Safety Control Under Accident Conditions

The magnitude of release of radioactive material to the atmosphere as a result of a reactor accident could vary; and the nuclear designers, supervised by regulating authorities, seek to reduce the probability of any large release of radioactivity to a very low level. The most extreme failures, many assumed to be occurring simultaneously, are postulated for purposes of analyzing the effects of a reactor accident, and regulating authorities insist that even in the most adverse circumstances, the direct effects of a maximum release from a large reactor at distances greater than 1,000 meters from the plant will not exceed limits established by the ICRP.

### 3.3.3 Safety Control in Canada

In Canada, the Atomic Energy Control Act of 1946 puts control of reactor licensing in the hands of Atomic Energy Control Board; and a Board license is required for the construction and operation of any nuclear reactor. The Board in turn has established a Reactor Safety Advisory Committee composed of experts in the field of nuclear health and safety, plus technical representatives of provincial and municipal organizations, who are invited to join the Committee for discussions on subjects of particular interest to their principals. No reactor may be licensed without first being reviewed by the Committee.

The Atomic Energy Control Board's jurisdiction also covers the import and export of nuclear materials and the transport of the same by road.

The subject is further discussed under "Licensing" in Section 7.

## 3.4 ENVIRONMENTAL ASPECTS OF NUCLEAR POWER

### 3.4.1 Thermal Effects

In steam power plants, thermal efficiencies that are economically justifiable range up to 40 percent in fossil fuel plants and 34 percent in nuclear plants at optimum conditions. This means a large portion of the heat released is waste and has to be transferred to the environment. Whereas in a fossil fuel plant, part of this wasted heat is discharged to the atmosphere through a stack, in a nuclear plant almost all (99 percent) of the wasted heat is rejected to the cooling water.

Steam conditions and heat rates in a nuclear power plant vary from those of conventional fossil fuel plants. Whereas steam conditions for a lignite coal fired plant as in Boundary Dam Station are 1800 psi/1000°F/1000°F reheat nuclear power reactors produce steam at 600 - 1000 psi and 500°F - 600°F.

The net heat rates for a coal fired unit burning lignite as in Boundary Dam Station and a nuclear plant, both of 600 MW unit size, would be in the order of 10,100 BTU/KWH and 11,700 BTU/KWH respectively. The higher heat rate of the nuclear plant reflects the lower thermal efficiency due to the lower steam conditions. Thus in a nuclear plant, a larger portion of the heat released is wasted and almost all of it is discharged to the cooling water. Consequently, the thermal discharge to the cooling water from a nuclear power plant is about 60 percent higher than in a conventional thermal plant, and results in the discharge of a considerably larger volume of cooling water. For example, the turbine in a nuclear power plant of 600 MW unit size would probably be equipped with a condenser utilizing a maximum flow of 426,000 USgpm and raising the water temperature by about 24°F. This would correspond to a thermal discharge of $4.7 \times 10^9$ BTU/hour, and would call for special attention to thermal discharges.

### 3.4.2 Radiation Effects

Recent objections raised by environmentalists to nuclear power are usually based on the premise that all artificially created radioactivity is bad and should not be permitted. Behind this attitude is the belief that even small doses of radiation initiate the genetic changes that form the basis of the evolutionary process, and it is considered undesirable to speed up these changes. Others claim a correlation between the discovery of artificial radioactivity and the incidence of diseases such as leukemia. Most certainly, it is universally agreed that undesirable quantities of radioactivity were released to the environment in the days of unlimited testing of nuclear weapons. The debate becomes a subjective and rather emotional one because the alleged effects are not measurable except on a statistical basis over a long period of time.

The answer to these fears is that nuclear power plants release to the environment only a small fraction of the radioactivity which is set as the permissible limit by international agreement, and that these limits themselves are small by comparison with the levels of radioactivity which exist in nature. The United States Public Health Service, for example, carried out extensive long-term studies of the environs of three power reactors, and concluded that after 10 years of operation, no evidence can be found of an increase in the exposure of the surrounding population above that received from natural sources.

A nuclear power plant does not, of course, emit any radiation directly. Within the reactor building, there are areas of high radiation, and elaborate precautions are taken to ensure that the plant operators are not exposed to harmful doses. Nevertheless, an operator is permitted to receive a considerably higher dose than are members of the general public, this higher limitation being still well below the point at which there is any measurable biological effect.

A more serious risk to the population would exist if there were not adequate restrictions on the discharge of radioactive effluent. This may be liquid or gaseous. Current practice is to allow very dilute quantities of radioactive effluent to be discharged, either up stacks or into the cooling water outfall. These discharges are continuously monitored and are only permitted if the level of radioactivity is below prescribed limits which are well below safety levels. Means exist to halt such discharges instantly unless they are absolutely safe.

In the case of liquid effluents, special care must be taken. Most radioactivity dies away to nothing fairly rapidly, but there are certain long-lived isotopes, such as those of strontium and cobalt, which are especially dangerous to man and other creatures because of their long-term effect if ingested. If fish or crustacea live near a point of discharge of effluent there is a possibility of a cumulative build-up of radioactivity in their bodies. This "life-chain" effect is taken into account when the location of a nuclear power plant is being sought, and continuous measurements are taken of all effects on the environment including the possibility of "build-up".

It is important to note that there is no chance of radioactivity going undetected unless there is total instrument failure. The instrumentation in common usage is capable of measuring radiation of all kinds in the most minute quantities. In fact, nuclear instrumentation has achieved such amazing sensitivity that it is now used in science to study phenomena which would be undetectable by any other means. Carbon-14 dating of prehistoric artifacts is a good example.

Another point to remember about radioactive discharges is that it is technically possible to prevent any discharge at all. This is achieved by filtration, concentration, and similar processing until the end product is suitable for permanent burial. However, as with all other industrial effluents, it is current practice to dilute and discharge certain low-level wastes if it is more economic to do so, and if current scientific opinion agrees that no harm is being caused to the environment. The fact that currently prescribed levels continue to be subject of debate and controversy is in itself, reassuring.

## 4.0

## NUCLEAR POWER DEVELOPMENT IN CANADA

# 4.0 NUCLEAR POWER DEVELOPMENT IN CANADA

## 4.1 EARLY HISTORY

The principal power reactors available in the western world have evolved from the reactor programs of the U.S.A., Great Britain and Canada. The developments in these three countries had a common start which originated from wartime requirements. They subsequently followed different paths, each country selecting a reactor for peace time development that seemed best suited to its particular circumstances.

The British reactor was developed from the early experience in the large graphite moderated ractors which were used in the production of materials for the defence program. Reactor designs were selected to produce plutonium and also give electric power as a by-product.

In the U.S.A., there was not the immediate need for nuclear power as was the case in the United Kingdom because of the plentiful supply of other fuels. Due to the nuclear weapon program, large-scale enrichment facilities had been developed and stocks of fuel accumulated. Moreover, a compact nuclear propulsion plant was required for the Navy, and it was obvious that the light water moderated and cooled ractor would be a logical choice. When it was later decided to build a land based power station, the first type of reactor to be applied was a scaled version of the propulsion reactor - hence the first pressurized water station at Shippingport.

War time research in Canada was concentrated on an investigation of the nuclear properties of heavy water, and the NRX reactor at Chalk River was developed for this purpose. It was the first reactor in the world outside the United States. Later, in the 1950's when Canada turned to nuclear power and developed the CANDU reactor, it was logical that a design based on the use of natural uranium for fuel and heavy water for moderation and cooling, similar to NRX, should be adopted. Such a course not only made maximum use of preceding experience, it also used natural uranium fuel which is in plentiful supply in this country.

The CANDU nuclear power plants that have been or are being developed are listed in Table 4-1. All are of the PHW type except that at Gentilly, which is BLW.

TABLE 4-1
CANDU POWER REACTORS

| Name | Place | Net Output MW | First Operation |
|---|---|---|---|
| NPD (Nuclear Power | Rolphton, Ontari | | |
| NPD (Nuclear Power Demonstration) | Rolphton, Ontario | 1 x 20 | 1962 |
| Douglas Point G.S. | Bruce County, Ontario | 1 x 208 | 1967 |
| Pickering G.S. | Pickering, Ontario | 4 x 508 | |
| | | Units 1 & 2 | 1971 |
| | | Unit 3 | 1972 |
| | | Unit 4 | 1973 |
| Gentilly | Gentilly, Quebec | 1 x 250 | 1971 |
| Bruce G.S. | Bruce County, Ontario | 4 x 750 | 1976-1979 |
| OVERSEAS | | | |
| Kanupp | Karachi, Pakistan | 1 x 125 | 1 1971 |
| RAPP | Rajasthan, India | 2 x 200 | |
| | | Unit 1 | 1972 |
| | | Unit 2 | 1974 |
| Kalpakkam | Madras, India | 1 x 200 | 1975 |

## 4.2 NPD

Canada's first power reactor, NPD was conceived in 1954 and built at Rolphton, Ontario, a few miles from the AECL Chalk River Nuclear Laboratories. It began operation in 1962. A partnership consisting of Atomic Energy of Canada Limited (AECL), Canadian General Electric Company Limited (CGE) and the Hydroelectric Power Commission of Ontario (Ontario Hydro) was responsible for both design and construction.

The NPD reactor pioneered all the concepts currently used in the CANDU-PHW line of reactors; moderation by cool, semi-stagnant heavy water; heat removal by high temperature pressurized heavy water; horizontal pressure tubes with bi-directional on-load refuelling and fuel bundles designed to suit. Its net rating is 20 MW(e).(1)

## 4.3 DOUGLAS POINT

The first full-scale prototype CANDU-PHW power station was built at Douglas Point, near Kincardine, Ontario, and achieved initial criticality in 1966. It is owned by AECL and the Power Projects Division of AECL was responsible for design of the reactor. Ontario Hydro designed the conventional plant and provided the construction force. They now operate the station and have the option to purchase it. The actual net output is 208 MW(e).

The Douglas Point design was based on that of NPD, but because of its much larger size, a great deal of additional development was required.

Moreover, the design was started before NPD began operation. Hence, the experience to be gained from the latter only became available for the later stages of the work at Douglas Point.

Three 200 MW(e) units, similar to the 208 MW(e) at Douglas Point are under construction in India at RAPP and Kalpakkam. These have benefited from the operation at Douglas Point and have incorporated the various corrective measures found necessary.

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(1) Electrical capacity of nuclear power station is commonly indicated in terms of ME(e) to avoid confusion with thermal capacity which is also measured in electrical equivalents, i.e. MW (thermal).

## 4.4 PICKERING

The first full commercial CANDU-PHW station is the four-unit Pickering Generating Station near Toronto, each unit having a design net output of 508 MW(e). The station is wholly owned and operated by Ontario Hydro although the Federal Government made available part of the capital cost in a loan. AECL provided the design of the nuclear steam supply system, and Ontario Hydro designed the remainder of the station. Ontario Hydro also provided management of the project and constructed the plant.

The experience with Douglas Point enabled Ontario Hydro and AECL to incorporate in Pickering, design changes to overcome the serious problems of heavy water loss and fuelling machine operation. It also facilitated the development of commissioning procedures which improved the reliability of construction scheduling. This is particularly important, because the construction time of nuclear stations has been responsible for serious increases in capital cost of plants throughout the world.

Unit 1 at Pickering produced first power and was synchronized to the grid on April 4, 1971. It produced full power on May 30, 1971, and to December 31, 1971 had an average capacity factor (CF) of 82 percent.

Unit 2 was commissioned even more rapidly with first power October 6, 1971, full power November 7, 1971; and for November and December, the capacity factor averaged over 90 percent.

## 4.5 KANUPP

This CANDU-PHW station was designed and constructed by Canadian General Electric Company near Karachi in Pakistan. It has a rated net output of 125 MW(e). Construction was completed in 1971, and net power achieved towards the end of that year. Although basically similar to Douglas Point in concept, the KANUPP design incorporates many innovations which have led to lower costs and ease of construction and commissioning. This experience is useful for future plant design.

## 4.6 GENTILLY

The Gentilly nuclear power plant near Three Rivers, Quebec, is the prototype CANDU-BLW station. It was designed and built by AECL for and with the cooperation of Hydro-Quebec under a contractual arrangement similar to that applied at Douglas Point. It contains one BLW unit with 250 MW(e) net rated capacity, which is currently being commissioned. This unit uses boiling light (i.e. ordinary) water as the coolant, and its design objectives are to reduce capital cost by reducing the heavy water inventory, and to reduce operating costs by eliminating heavy water losses. The boiling feature introduces control problems which can only be solved by application of the prototype. Hence, AECL has stated that a decision to exploit the design commercially will not be made until about two years of operation have been evaluated, i.e. say 1974.

## 4.7 BRUCE

The latest nuclear power plant being built by Ontario Hydro is the four-unit CANDU-PHW station at Bruce, adjacent to Douglas Point, each unit having a design net output of 750 MW(e). The units, like those at Pickering, are of the horizontal pressure tube type, but incorporate many innovations in the design and method of construction of the reactor. The reactor design is once again by AECL with Ontario Hydro designing the remainder of the station and carrying out the construction and commissioning. The first unit of Bruce is scheduled for operation in 1976. It will be one of the largest nuclear stations in the world when completed.

# 5.0

# FUTURE PROSPECTS FOR NUCLEAR POWER IN CANADA

## 5.0 FUTURE PROSPECTS FOR NUCLEAR POWER IN CANADA

### 5.1 PROBLEMS INHERENT IN THE NUCLEAR POWER INDUSTRY

The trend to larger units for both conventional thermal and nuclear power plants has been dictated by the prospect for enhanced economies on the one hand, and the practical requirements of a power market growing at a more or less constant exponential rate on the other. As outlined in Section 4, Ontario Hydro progressed from the 200 MW(e) Douglas Point unit, through the 500 MW(e) units at Pickering to the 750 MW(e) units at Bruce in a decade. The progress in the sizes of both conventional and nuclear units in other countries is similarly rapid; and as a result, experience the world over must be gained in prototype units and quickly incorporated in those that follows. And this circumstance in turn makes the commercial aspect of the problem more difficult by inducing a reluctance on the part of electric utilities to buy other than second generation units of proven reliability, regardless of type. The reluctance, of course, is greater in the case of nuclear units because in addition to the large increases in unit capacity, nuclear designers must also develop new reactor types at the same time.

It follows from the situation described in the preceding paragraph, that those countries in which a succession of orders for new plants can be obtained will make greater progress than one in which orders are few and far between, regardless of the intrinsic merits of the power system employed; and this places Canada at a disadvantage. It is by far the smallest country in the world (in terms of population and industrial development) that is attempting an original nuclear power program. Several other countries, notably France and Sweden, began such an independent effort, but later abandoned it.

## 5.2 CURRENT SITUATION IN CANADA

To date, the Pickering PHW units are the only fully commercial second generation CANDU reactors in service in Canada. Their successful commissioning and the early declarations of "in service" status by Ontario Hydro, however are reassuring. It is clear that the experience from Douglas Point and elsewhere has been successfully applied to produce acceptable improvements in construction and commissioning schedules as well as in operability. Hence, these units can now be considered to have reached maturity and to be acceptable for firm power generation in a major utility. Heavy water availability would appear to be the major remaining problem.

If Canada can obtain a good commercial market for its reactors, so successfully demonstrated at Pickering, it will provide incentive (and funds) for the development of improvements to the CANDU system - of which there are an increasing number of prospects. The principal ones are noted below.

(1) The CANDU-BLW, as at Gentilly. As mentioned in Section 4.6, the BLW reactor may be competitive, but it requires at least two years in operation before it can gain commercial acceptance.

(2) An advanced CANDU-BLW. In this reactor plutonium recovered from the operation of earlier CANDU reactors would be used to enrich the fuel elements. A much smaller core would thus become possible. For example, the core for a 750 MW unit would be no larger than that for the 250 MW unit at Gentilly.

(3) The OCR or organic-cooled reactor. This reactor is still in the research stage as ACEL test reactor WR-1 at Whiteshell, Manitoba, but its excellent performance over the past five years has given its proponents great confidence in it. All water-cooled reactors have high radiation fields around the primary circuit while in operation, so that on-load maintenance is difficult or impossible. The organic coolant develops negligible radioactivity of this type. In addition, it can be run at higher temperatures to produce higher thermal efficiency in the prime mover, and hence reduce the discharge of waste heat from the station.

(4) The Valu-Breeder. This reactor exploits the special nuclear characteristics of thorium and offers fuel costs equal to those of the fast breeder reactor.

In addition, there are many potential minor improvements, especially with respect to fuel.

## 5.3 FUTURE PROSPECTS

Indications from bids from around the world are that at present, there are only two basic systems in the nuclear race; the American enriched light water reactors and the Canadian CANDU reactors. The advantage of one system over the other is small and the trends are in the direction of improving the competitive position of the CANDU system.

Many leaders of the scientific community in the U.S.A. have expressed concern that the commercial success of the light water reactor has stultified research and virtually eliminated all serious competition among reactor types. The light water reactor is inefficient in its use of natural resource, hence the USAEC has been trying for years to sponsor development of the fast breeder reactor, which is claimed by many to be the ultimate in nuclear power. However, opposition to the FBR is highly vocal with respect to both technology and safety.

The Canadian view is that the breeder system is simply not needed for many decades in view of the larger uranium and thorium reserves in Canada and a Canadian reactor system which can efficiently burn these fuels. Even in a global standpoint, it could be argued that the neutron economy of the heavy water reactor is so high that sufficient energy can be extracted from the world's uranium reserves to ensure power at competitive price until at least the end of the century. By that time, it is almost certain that scientific research will have turned up other sources of energy, probably thermonuclear or fusion power, which will render all fission reactors obsolete.

It is fair to say that the CANDU system, built by Canadian industry, would be capable of meeting the Canadian demands for electric power for the predictable future.

# 6.0 NUCLEAR POWER FOR SASKATCHEWAN

## 6.0 NUCLEAR POWER FOR SASKATCHEWAN

### 6.1 GENERAL

The rapid advances being made in nuclear power through changes in technology and increases in unit sizes lead to the conclusion that if a region or system has sufficient resources of conventional power for development at reasonable cost, they should be used to postpone the entry into the nuclear field to gain advantage of the maximum advances in technology made by others.

However, the resources of conventional power, no matter how large, are nonetheless finite. Hydro power is available in perpetuity, but in a specific and limited amount, and supplies of lignite are large but finite, particularly the size required to support major generating facilities. Hence, if the power demands in the Province continue to expand, even at a declining rate, the time will eventually come when it will no longer be possible to ignore nuclear power. Moreover, this eventuality could be hastened if advancing technology in the processing of lignite, such as gasification were to so enhance the value of these fuels as to make it uneconomical to burn them under central power station boilers.

The power requirements of the Province, at an anticipated 6 percent/year peak load growth, would demand the addition of 300 MW capacity every three years in the early 1980's and every two years in the late 1980's. This would appear to be relatively modest in comparison with the sizes of nuclear power plants now accepted as normal. Units of 300 MW or less would be much more expensive to build and operate than those of larger sizes, but they could readily be made available if this penalty were accepted.

### 6.2 METHODS OF CONTRACTING

It should be noted that since CGE stopped marketing complete reactors, there is no Canadian supplier in the private sector able to offer such a service. AECL is fulfilling this role as an outgrowth of the way in which Douglas Point and Gentilly were built, but it does not manufacture.

AECL designed the reactors for Douglas Point and Gentilly, and specified the reactor components for manufacture by private industry to its design. AECL also designed the reactors for Pickering and Bruce, acting as consultants to Ontario Hydro, with the latter doing their own procurement and contracting. In all of these stations, the remainder, or conventional parts of equipment and plant were designed by others. For the Ontario Hydro projects at Douglas Point, Pickering and Bruce, Ontario Hydro carried out the remainder of the design. Ontario Hydro were also the general contractors for the construction of the stations. At Gentilly, the remainder of the design was done by outside consultants, who also supervised the construction. Hydro-Quebec were the contractors.

For the overseas work, AECL does the marketing and will contract for reactor design, supply and commissioning. If the client so requires, AECL will also undertake the contract for the entire station, in which case, they would design the reactor and engage the services of consultants for the remainder of the engineering work, including project management.

## 6.3 EFFECTS OF A NUCLEAR POWER PROGRAM ON SASKATCHEWAN POWER CORPORATION

A nuclear power station is more complex than a conventional thermal power station in operation, maintenance and administration, and so staff with specialized training will be required both at the plant and at the head office. The only two utilities in Canada having nuclear power programs, namely, Ontario Hydro and Hydro Quebec, have different approaches to the problem of staffing with specialized training. Ontario Hydro, due to the extensive nature of their nuclear program, have a large in-house organization specialized in nuclear power generation, and carry out their own design, planning, construction and operation of the nuclear power plants, except for the design of the reactors, which is done by AECL. On the other hand, Hydro Quebec, due to the limited nature of their nuclear program, have a small in-house organization for operation, maintenance and administration. The design and construction supervision are done by outside agencies.

### 6.3.1 Operating Staff

The operating staff can be divided into four groups; key operating personnel, specialists, technicians and clerical and labour.

The key operating personnel would consist of station superintendent, production superintendent, technical engineer, shift supervisors and health physicist. The first three should be professional engineers, the shift supervisors should be engineering technologists and the health physicist should be a technologist. All of them except the health physicist should have 4 to 5 years of power plant experience, preferably including nuclear field. The health physicist should have biological and radiological experience.

The specialist group would include plant chemists, physics technologist, electrical/mechanical technologist and radiation control supervisor. They should be qualified and with two years' experience in their respective fields.

Technician groups of plant personnel would be the largest in total number and would consist of operators, maintainers and laboratory assistants. The first and second operators should be technicians with 5 years of experience as operator of reactor and/or thermal power plant. The control maintainer supervisor and control technician should be technicians with technical experience with electrical and control equipment. The assistants should be high school graduates with some power station experience.

Clerical and labour groups would include security guards and personnel to maintain necessary files and records and do other normal office services. Ability to understand the fundamentals of radiation protection would be required of this group.

A total of thirteen competent engineers/technologists should be adequate for a single unit 600 MW nuclear power plant. These thirteen men would be divided into two groups, the first group of ten including station superintendent, production superintendent, shift supervisors and health physicists. The second group of three would include the technical engineer and the control and mechanical maintenance supervisors. The second group would have more specialized training than the first group, but would start the training six months later. The first group training would include thirty months of background training such as practical operation in steam plants and preliminary nuclear engineering course, six months of practical and systems training at the Nuclear Training Centre, Rolphton, Ontario and six months with the designers for a station design familiarization course and assisting in the preparation of commissioning and operational documentation. The final phase of the training program would be at the station site working with the commissioning force and would include both groups of engineers/technologists.

The first group of operators and maintainers of at least ten men would undergo background training and instruction at a more practical level than the engineers/technologists for a period of 16 months, followed by six months of practical training at the Nuclear Training Centre and would join the engineers/technologists for the commissioning phase. A second group of operators and maintainers would start the training program six months later than the first group and join the more senior operators at the site where they will receive instructions on plant familiarization, and assist in commissioning and operation.

After the station is operational, a continuing training program is recommended to provide competent personnel for replacement of those who leave or who are promoted.

Figure 6-1 shows a typical nuclear station organization chart showing on the job training positions in dotted lines. The number of personnel in each category is shown thus (2).

## TYPICAL NUCLEAR STATION ORGANIZATION CHART
## SHOWING ON-THE-JOB TRAINING POSITIONS

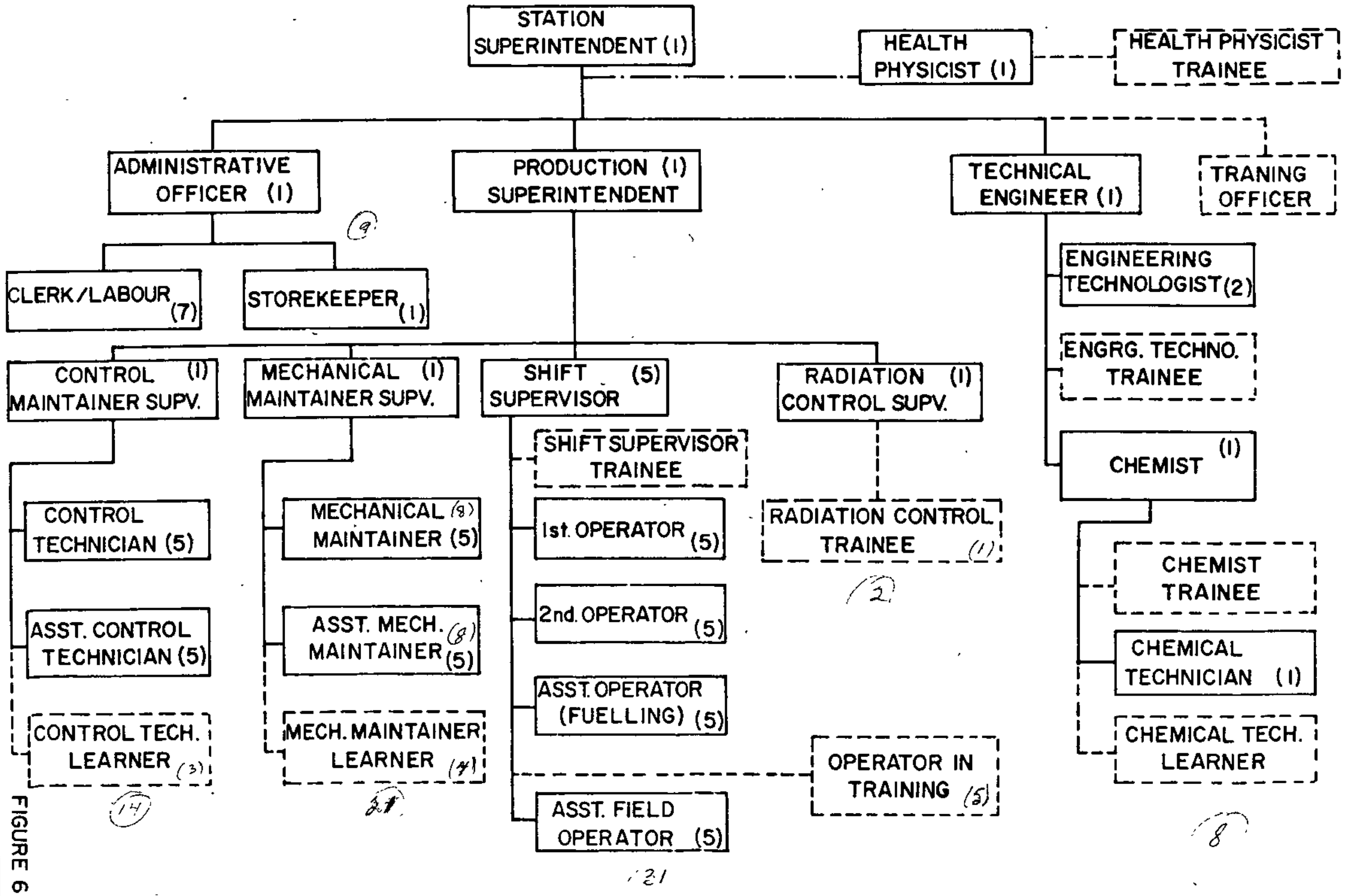

FIGURE 6-1

### 6.3.2 Head Office Staff

A nuclear power program would involve some additional specialized staff requirement in the head office of the Corporation also. Although most of the administrative work could be handled by the same administrative staff as required for a conventional thermal plant, the following will be special requirements.

1) A small health physics group of 3 people to oversee the health aspects of operating the plant.

2) A group of 3 people to look after the legal and safety aspects of the nuclear plant, and the Corporations' dealings with the Atomic Energy Control Board.

# 7.0 NUCLEAR POWER PLANT IN SASKATCHEWAN

## 7.0 NUCLEAR POWER PLANT IN SASKATCHEWAN

### 7.1 GENERAL

For the purpose of this study, a nuclear power plant of 600 MW(e) capacity has been considered in a central location in Saskatchewan. Unlike conventional thermal plants, the economics of a nuclear power plant are affected in a negligible way by its location relative to the source of fuel. Two factors which influence the location of a nuclear power plant are an abundant supply of cooling water close to the plant and the load centre of the system.

The unit size of 600 MW(e) was chosen because it is a modern plant incorporating proven features from Pickering and improvements from Bruce and is similar to those proposed for Gentilly II. A smaller unit of 200 - 300 MW(e) although feasible, would be prohibitive in cost. The smaller units in Canada at Douglas Point and Gentilly I were built as prototype units.

The report of Canatom Ltd., Nuclear Power Consultants "Saskatchewan Power Corporation - Nuclear Power Plant Study" is included as part of this section. The report covers a description of the plant and preliminary estimate for 600 MW(e) unit, additional cost for provision for extending to a second unit of 600 MW(e) and cost of a second unit of 600 MW(e). The report also covers the licensing requirements for a nuclear power plant development.

# SASKATCHEWAN POWER CORPORATION

# NUCLEAR POWER PLANT STUDY

CANATOM LTD.

1134 St. Catherine St. West
Montreal, Quebec

SASKATCHEWAN POWER CORPORATION
NUCLEAR POWER PLANT STUDY

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5.0 PROJECT SCHEDULE

## 1.0 INTRODUCTION

This report contains a brief description, conceptual layout, summary cost estimates and schedule for a 600 MW(e) nuclear power plant at a typical site in Saskatchewan. Also included, is a section dealing with the Atomic Energy Control Board's requirements for licensing of nuclear power plants. Provision is made for the addition of a second unit adjacent to the first, and utilizing certain common facilities. The report is based on technical data and costs developed for a similar plant now being considered for a location in eastern Canada.

The proposed 600 megawatt station is designed for commercial baseload operation. Its source of power is an AECL designed CANDU nuclear reactor of the pressurized heavy water (PHW) type, which has been used in all Canadian designed nuclear power stations built to date, with the sole exception of Gentilly I. This type of reactor uses heavy water for the moderator and for the heat transport fluid. The fuel is natural uranium supplied in the form of bundles which are loaded into and removed from the reactor "on power". A closed loop cooling circuit is provided to transfer the heat from the fuel and produce light water steam in heat-exchanger boilers. The turbine generator and auxiliaries and the remainder of the plant are designed to meet nuclear power plant requirements.

The project schedule (Figure 5-1) indicates that a period of 72 months is required from the start of engineering to commercial operation. This schedule is based on experience with construction of other nuclear power plants.

In selecting the PHW design, AECL recognizes the desire of electrical utilities to install tried and proven equipment. The nuclear steam supply, therefore, uses equipment similar to that which has been developed for stations now in operation or under construction having a total output in excess of 6000 MW(e).

With the assistance of AECL Canadian industry has built up considerable experience in the manufacture of components for nuclear power plants. The major components are the calandria, end shields, shield tank, steam generators, primary coolant pumps and the fuelling machines.

AECL designs and specifies the equipment and in their laboratories conduct applied research, development and testing to support existing plants and improve technology for future plants. They have also assisted industry in achieving a manufacturing capability by means of development contracts.

Two examples of the collaboration between AECL and industry are the development of the fuelling machine and the CANDU reactor fuel, the design and manufacture of which incorporate a large amount of research and development by both AECL and the manufacturers.

During Construction, a work force peaking at about 600 to 800 men will be required. For the mechanical work, a number of skills are required for erection and alignment of the major equipment to a high degree of accuracy and for the large amount of high quality field welding necessary to meet stringent requirements for leak tightness.

## 2.0 DESCRIPTION

### 2.1 SITE

No specific site has been considered for the location of the nuclear power plant. The estimate has, however, been based on a location adjacent to a large body of water such as Diefenbaker Lake. The alternative to this would be a site with a man-made pond of about 2000 acres in an area with make-up supply and blowdown systems.

### 2.2 BUILDING AND STRUCTURES

The reactor and its closely associated systems and services are housed in the Reactor Building. This is a cylindrical post-tensioned concrete structure designed for containment and for radiation shielding.

A Service Building of conventional reinforced concrete and structural steel construction, houses a number of supporting systems and services, and the station control centre. Other buildings, also of conventional design, include the turbine building, the pumphouse and an administration building.

## 2.3 REACTOR, BOILER AND AUXILIARIES

### 2.3.1 Reactor

The reactor consists primarily of a tubed calandria vessel containing the heavy water moderator/reflector. It is penetrated by 380 fuel channels containing the fuel and hot, high pressure heavy water "coolant". The fuel channels are centrally located inside the calandria tube and are separated from the calandria tubes by a small gas annulus.

End shields, which are an integral part of the calandria vessel, provide shut-down shielding for each end of the reactor. The fuel channels penetrate these end shields and are supported by them. The calandria is located inside a concrete reactor vault which is filled with light water. The water provides additional shielding and also maintains the calandria shell at essentially constant temperature. The steel end shields are located in the end openings of the reactor vault, and form part of the vault enclosure. Flux monitoring devices are provided in and around the core to measure reactivity, and reactivity control devices are located in the reactor to control the nuclear reaction.

Two independent reactor shutdown systems are provided, each of which is capable of shutting down the reactor under the maximum credible accident condition. The first system is a bank of shut-off rods which drop into the core by gravity, after receipt of a shutdown signal from the protective system instrumentation. The second shutdown system uses the injection of a neutron absorbing solution into the moderator. It is actuated by a much smaller number of variables with higher trip set points than those of the shut-off rod system.

### 2.3.2 Primary Heat Transport System

The primary heat transport system is designed to circulate pressurized heavy water through the fuel channels to remove the heat produced in the fuel. This heat is transferred to ordinary water in the heat exchangers (boilers) located inside the reactor building. The light water in the boiler is at a lower pressure and therefore boils, producing the steam which is used to drive the turbine-generator.

The primary heat transport system includes the circulation pumps, headers, feeder pipes to and from each fuel channel, the primary side of the boilers, and a pressurizer. System pressure control is provided by the pressurizer. Water chemistry is closely controlled to limit the build-up of active corrosion products. Close attention is given to minimizing the escape of heavy water from the system and the collection of heavy water liquid or vapour which does escape.

### 2.3.3 Moderator System

The heavy water moderator is circulated through the calandria in a warm, low pressure system. The moderator heat exchangers remove heat generated in the moderator by radiation and by transfer from the primary heat transport system. Helium is used as a cover gas over the heavy water. Chemistry control of the moderator water is maintained by the moderator purification circuit.

### 2.3.4 Auxiliary Systems

There are a number of auxiliary systems associated with the heat transport, moderator, and reactor control systems. The most significant auxiliary system are as follows:

a) Reactor vault water-shield cooling.

b) Containment dousing system.

c) Emergency cooling of fuel.

d) Spent fuel bay circulation system

e) Light water zonal flux control system.

f) Supply of gas for the annulus between the pressure tubes and the calandria tubes.

g) Moderator liquid poison system.

h) Reactor shutdown cooling system.

i) Resin handling systems required by the moderator and heat transport purification circuits.

j) $D_2O$ collection systems.

k) $D_2O$ cleanup and upgrading equipment.

### 2.3.5 Fuel Handling

The reactor is refuelled on-power by two remotely operated fuelling machines, one at each end of the horizontally tubed reactor. The fuelling machines, working at opposite ends of the same fuel channel, remove spent fuel and insert new fuel while the reactor continues to operate at power.

New fuel is brought into the Reactor Building from a storage area in the Service Building via the main air lock and is loaded into the fuelling machine.

The spent fuel is transferred under water, through a canal to the Spent Fuel Bay which is located in the Service Building. The Spent Fuel Bay has a storage capacity for ten years' accumulation of spent fuel.

### 2.3.6 Fuel

The fuel is similar to that being provided for the Bruce reactors. The Bruce fuel has evolved from the fuel used in the NPD, Douglas Point, and Pickering reactors.

The fuel is in the form of natural uranium dioxide pellets, sheathed and sealed in zirconium alloy tubes. These tubes are assembled between end plates to form fuel bundles. Each of the 380 fuel channels contains 12 bundles, to give a total of 4,560 bundles in the reactor.

## 2.4 TURBINE GENERATOR AND AUXILIARIES

The electric power generating plant assumed for this study consists of a tandem compound (single shaft) turbine generator unit operating at 1800 rpm, on a steam cycle employing external moisture separation and live steam reheat between the high pressure and low pressure sections. The plant includes a twin shell steam surface condenser with tubes running transversely to the turbine axis. The regenerative feed water heating system consists of three low pressure stages, a deaerator and one high pressure stage.

The generator is a four pole, hydrogen/water cooled type and is provided with a static excitation system.

All other turbine generator plant auxiliaries are included.

## 2.5 ELECTRIC POWER SYSTEMS

The main power output system consists of the generator, isolated phase bus duct, generator transformer and station switchyard.

The unit service class IV supply is tapped off the isolated phase bus duct and the station service class IV supply is fed from the duct via the station switchyard.

Plant shutdown systems can be supplied from class III busses which are fed by back-up diesel or gas turbine driven generator units.

Plant safety and protective systems are supplied from station batteries either directly (class I DC) or through inverters (class II AC).

## 2.6 INSTRUMENTATION AND CONTROL

The amount of automation provided is sufficient to ensure safe and reliable operation. Where centralized control is necessary, control stations and visual indicators are located in the control room. Control room instrumentation also includes communication systems and computer print-outs and CRT displays.

Provision is made for continuous operation of certain instrumentation and control circuitry in case of loss of normal station service power by means of triplicated systems which are fed from class I or class II power sources. Triplicated instrument signals are run over separate routes between sensing device and control equipment. A Dual Computer System forms part of the station control equipment.

## 2.7 STATION SERVICE

The station service systems include condenser circulating water and process water systems, fire protection systems, domestic water systems, demineralized water system, active and inactive drainage systems, sewage system, ventilating and air conditioning systems, compressed air and other compressed gas services, materials handling equipment, miscellaneous equipment (laundry, etc.) and waste management systems.

## 3.0 LICENSING

### 3.1 THE AECB AND ITS REQUIREMENTS

The Atomic Energy Control Act requires that the Atomic Energy Control Board (AECB) exercises control over nuclear power reactors in Canada. It is not permissible even to start pouring concrete for the foundations of a nuclear power station before a license has been issued. The Board strongly recommends informal consultation at a very early stage on any proposed nuclear porject, in order to avoid wasting work on concepts which are ultimately found to be unacceptable. This is particularly true of the selection of a site.

Construction is defined as beginning with the pouring of concrete or erecting of essential foundations for the reactor proper. Issuance of a construction license implies approval of the general design or design specifications as suitable for the site in question, but it does not mean that an operating license will automatically be granted. In Canada, details of design are normally still under consideration when civil construction begins and these details are kept under review as construction proceeds.

The operating license authorizes operation of a plant within certain defined limits, including the use in the reactor of fuel and heavy water which must be obtained under separate Board orders. Start-up and the early operation are usually covered by an interim operating license with special conditions and restrictions.

It is important to note that a license covers a specific reactor in a specific location. There is no such thing as a site licensed to take any kind of nuclear power plant. In practice, 90 percent of the discussion will be eliminated if the applicant states that he intends to build a copy of a reactor being built elsewhere, which has already been subjected to Board examination. In such a case, the licensing formalities would be primarily concentrated on the suitability of the site.

"Site Approval" is not a formal licensing step, and it would be sufficient to obtain a letter from the Board saying that they see no obvious difficulties in the way of securing a construction license, on the basis of the general facts submitted.

## 3.2 THE CONSTRUCTION LICENSE

More detailed information pertaining to the site, such as land use, population, principal sources and movements of water, water usage, meteorological conditions, and geology is required when a formal request is made for a Construction License. Technical information on the reactor and auxiliary equipment is also required with the application for a Construction License, and this is usually submitted in a comprehensive report sometimes termed a "Safety Report" combining the design description and specifications and the preliminary analyses of accidents. Although many aspects of the design may not be firm, the design description and specifications must provide a clear picture of the plant design and be sufficiently complete to enable independent analyses to be done. The Board has prepared, as a guide for prospective licensees, a document entitled "Requirements for Safety Report".

A Safety Report is a massive and highly technical document. It is submitted by and in the name of the utility who wants to build the power station, but in practice, the discussion on reactor safety is written by the reactor designer and others who have contributed to the overall design. Unless Saskatchewan made special arrangements to build a prototype reactor with federal support (like Gentilly I in Quebec), it is more probable that the reactor would be a standardized design already in operation or in construction elsewhere. In this case, the Board will have already reviewed and approved the basic design, and will only be concerned with those aspects peculiar to the particular project which will be mostly concerned with the site - e.g. the foundations, the seismic nature of the area, and so on.

The granting of a construction license does not imply acceptance of every argument or conclusion in the Safety Report. Subsequent submissions and revision to the Safety Report are required as the design progresses. The submission and acceptance of such information may be made a necessary condition for carrying the construction beyond a certain stage. In general, the design descriptions and supporting analyses of major reactor systems must be submitted well before these systems are installed. From time to time throughout the period of design and construction, the Reactor Safety Advisory Committee and the Board staff meet with the applicants.

## 3.3 THE OPERATING LICENSE

The issuing of the Operating License implies acceptance by the Board of the safety aspects of the plant as constructed. Permission for full operation may be preceded by two substages of authorization:

(1) Permission to load fuel; and

(2) Permission to start up.

Prior to loading of fuel, all reactor systems affected by having the fuel in the reactor must have been satisfactorily tested as far as it is possible to do so. The permission to start up requires assurance that all reactor and auxiliary systems have been constructed according to the design and have been satisfactorily commissioned to the extent possible prior to start-up of the reactor. The design description and accident analyses must have been brought fully up-to-date. The operating procedures, the organization of staff and senior members of the operating staff, must all have been approved, and there must be an approved procedure for handling emergencies involving radiation.

The operating license includes (either by listing or by reference) conditions and restrictions on the level of radioactive effluents from the plant, the test conditions, and on allowable modifications to the plant and procedures. The Board receives formal annual reports on operation, radiation exposures and radioactive effluents, but the staff reviews these on a continuing basis.

## 3.4 SITE SELECTION IN PRACTICE

We have found the Board rather reluctant to issue guidelines on the selection of a suitable site. Their attitude is "Tell us where you would like to build a station and then we will tell you what we think of the idea". The Board's flexibility may be judged from the example of Pickering, which is by far the largest nuclear installation in the world built close to a major city. The Board were satisfied that the containment system, with its unique vacuum principle, offered adequate protection to the public. Ontario Hydro found that the cost of this special containment was fully justified by the savings in the cost of transmission.

One of the factors which would cause concern to the Board would be a proposal to build a station in an area of high seismic activity. This is unlikely to present a problem in the Prairies.

This chapter is based on a paper to the 1972 Annual Conference of the Canadian Nuclear Association by D.G. Hurst, President of the AECL.

## 4.0 COST ESTIMATES

### 4.1 CAPITAL COSTS

A cost estimate summary for a single unit 600 MW(e) nuclear power plant in Saskatchewan is given in Table 4-1. The costs associated with providing for a second 600 MW(e) unit adjacent to the first, and for addition of a second unit are also indicated. The costs were derived from a recent estimate prepared for a similar plant in Eastern Canada. Since this reference estimate did not include for a second unit, the second unit cost for this study was obtained by proportion from previous estimates and hence must be regarded as approximate.

The estimate has been prepared on the basis of preliminary layouts and designs using pricing information from suppliers for major equipment and materials and 1972 construction labour rates for the reference plant location in Eastern Canada. For the purpose of this estimate, the same overall cost of labour and materials was assumed for Saskatchewan.

Estimates are based on December 1972 prices with escalation at 8½% p.a. (compounded) shown separately and computed from cash flows for a 72 month schedule starting January 1, 1973. Although unrealistic, this starting date has been used in order to show costs for purposes of comparison, for an in-service date of January 1, 1979. Further escalation may be applied as necessary to adjust costs for in-service in mid-1979 or the end of 1979 as required.

Interest during construction (IDC) using an annual rate of 8% compounded was computed from estimated quarterly cash flows. The heavy water and fuel half charge carry interest charges for one year. Due to the large capital outlay, a delay in commissioning, after all monies are spent, would cost about $2 million per month in interest.

Duties on imported equipment and federal sales tax on materials and equipment not directly associated with the production of power are included. Provincial sales tax of 5% on all materials and equipment is also included.

Contingencies have been based on the estimated reliability of the quantities, unit prices and cost information used in the estimate, and some contingencies are included in the individual accounts.

A credit has been allowed in the cost estimate for power generated during the final commissioning and trial run stages prior to the plant going into commercial operation.

## 4.2 OPERATING COSTS

Operating costs including the annual cost of operation and maintenance, fuel costs and unit energy costs are given in Table 4-2.

Parameters used in computing unit energy costs are as follows:

| | |
|---|---|
| Station net capacity factor | 80% |
| Station life | 30 years |
| Station net output | 600 MW(e) |
| Station efficiency | 27.6% |
| Fixed charge rate on capital with interest at 8% p.a. | 8.88% |

# TABLE 4-1

## SASKATCHEWAN NUCLEAR POWER PLANT
## COST ESTIMATE SUMMARY
## DECEMBER 1972 PRICES - IN $10^6$ DOLLARS

| | First 600 MW(e) Unit | *Provision for 2nd 600 MW(e) Unit | Addition of 2nd 600 MW(e) Unit |
|---|---|---|---|
| Site and Improvements | 1.7 | | |
| Buildings and Structures | 21.7 | | |
| Reactor, Boiler & Auxiliaries | 35.7 | | |
| Turbine Generator and Auxiliaries | 33.5 | | |
| Electric Power System | 7.8 | | |
| Instrumentation & Control | 7.1 | | |
| Common Processes & Services | 12.8 | | |
| Construction Plant | 3.7 | | |
| Sub-Total | 124.0 | | |
| Heavy Water | 31.0 | | |
| Initial Fuel (half charge) | 2.4 | | |
| Allowance for spares | 1.5 | | |
| Health Equipment | 0.2 | | |
| Project Management, Engineering, Construction Management, Resident Engineering, Quality Control and Expediting | 52.7 | | |
| Commissioning | 8.1 | | |
| Insurance During Construction | 1.0 | | |
| Provincial Sales Tax | 6.1 | | |
| Contingencies | 14.0 | | |
| Sub-Total | 241.0 | 1.3 | 204.8 |
| Escalation at 8½% p.a. 1972-1979 | 58.8 | 0.4 | 50.0 |
| Interest During Construction at 8% p.a. | 68.2 | 0.4 | 58.0 |
| Total | 368.0 | 2.1 | 312.8 |
| Credit for Power generated during Construction | 3.9 | - | 3.9 |
| NET TOTAL 1979 COST | 364.1 | 2.1 | 308.9 |

* Cost of provision for second unit not included in first unit costs.

## TABLE 4-2

## OPERATING AND UNIT ENERGY COSTS

| | | Unit No. 1 | Unit No. 2 |
|---|---|---|---|
| 1. | CAPITAL | | |
| | Capital Cost | $364.1 \times 10^6$ | $311.0 \times 10^6$ |
| | Unit Capital Cost | 7.69 mils/kwhr | 6.57 mils/kwhr |
| 2. | FUEL COSTS | | |
| | Fuel Cost | $ 55/kg U | $ 55/kg U |
| | Fuel Burn-up | 7500 kw days per kg U | |
| | Unit Cost of Fuel | 1.11 mils/kwhr | 1.11 mils/kwhr |
| 3. | OPERATION AND MAINTENANCE COSTS | | |
| | Operating Staff | $2,165,000/yr | Assumed same as Unit No. 1 |
| | Insurance | 250,000 | |
| | Purchased Materials | 400,000 | |
| | Purchasing Services | 250,000 | |
| | Heavy Water Up-keep | 130,000 | |
| | Interest on 6 months fuel supply | 233,000 | |
| | TOTAL | $3,428,000/yr | |
| | Unit Cost of O & M | 0.82 mils/kwhr | 0.82 mils/kwhr |
| | TOTAL COST OF UNIT | 9.62 mils/kwhr | 8.50 mils/kwhr |

## 5.0 PROJECT SCHEDULE

The accompanying Summary Schedule, Figure 5-1 is presented in the form of a simplified network plotted to a time scale with intervals of one month, and shows only the main items and principal activities. The period from approval of the project to the start of commercial operation is assumed to be seventy two months.

The overall period for completion of the project is dictated primarily by delivery times of the major equipment and the subsequent time required for installation of the equipment and associated systems, and for commissioning. For this reason, orders for the major equipment must be placed as soon after project approval as possible. As a rule, the project completion date is not greatly influenced by the civil construction activity times and in scheduling construction the prime concern is to ensure that structures are ready for installation of equipment when it arrives. The Administration Building is completed about two years before commercial operation in order to provide office space for the commissioning staff and training of operators.

Scheduling of the electric power systems is restrained initially by the need for Station Service power at the start of Phase "A" commissioning. To meet this requirement, a portion of the switchyard and the Station Service supply and Distribution systems are installed prior to the start of Phase "A" commissioning. Installation of the remaining equipment is completed in time for the start of Phase "B" commissioning.

The various stages of commissioning are as follows:

1) Phase "A" commissioning:

   This stage is the commissioning of individual systems and items of equipment.

2) Fuel loading and approach to criticality.

3) Phase "B" commissioning:

   This includes commissioning of the complete station, criticality and testing at low power. First steam to turbine occurs during this phase.

4) Commissioning to full power.

5) Trial runs.

The critical items in the schedule are considered to be:

1) The procurement, delivery, erection and commissioning of the turbine generator.

2) Procurement, delivery, installation and commissioning of the reactor, the boilers and their associated systems.

3) Activities related to the reactor computer system and the fuel handling system.

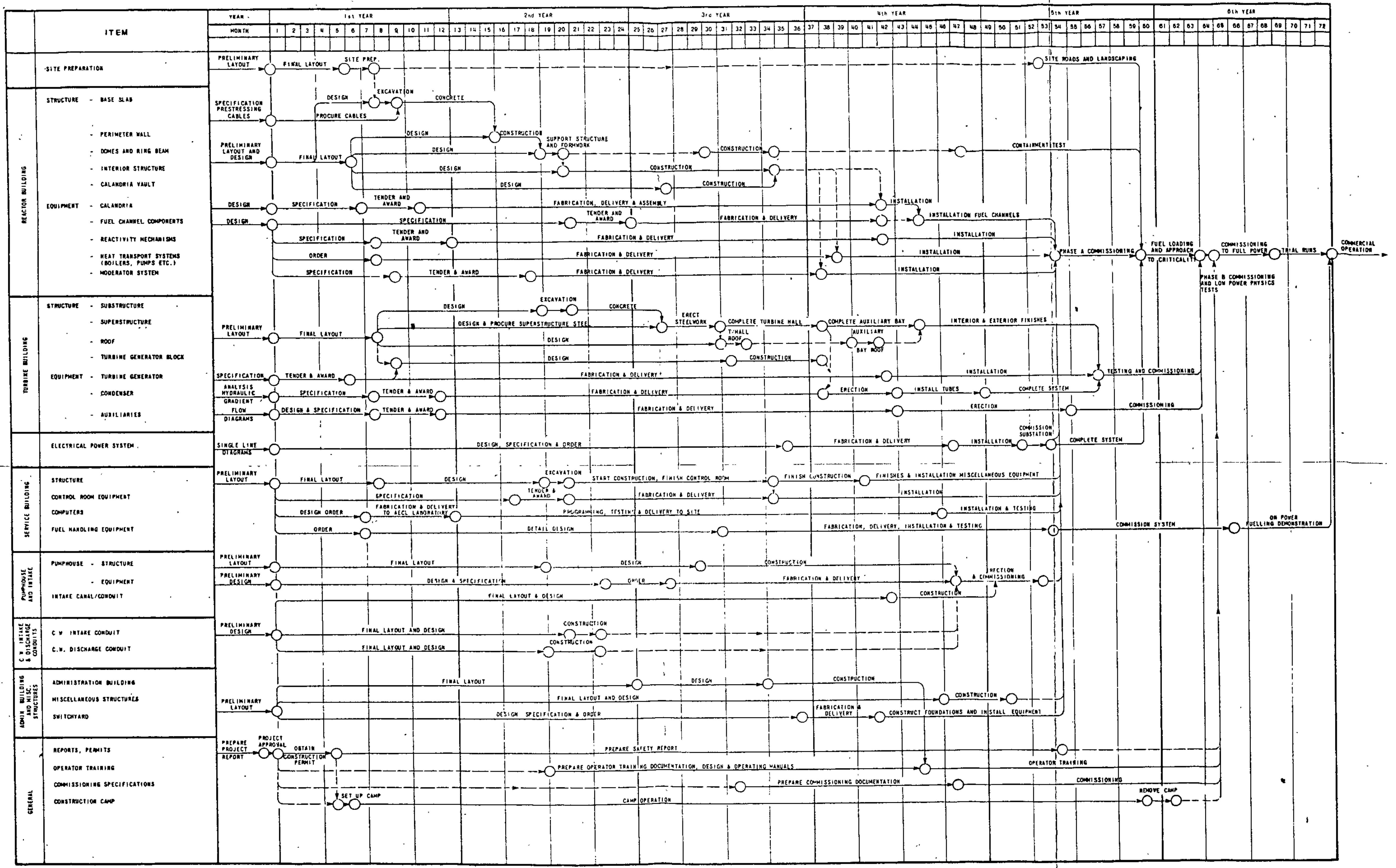

FIG. 5-1 PROJECT SCHEDULE