DOUGLAS POINT
NUCLEAR POWER STATION

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First full-scale nuclear plant takes shape

Many important features have been decided recently on the design of CANDU. Here they are spelled out in detail and related to the whole design picture.

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The decision to proceed with the design and construction of a full-scale nuclear power station in Canada was made in mid-1959. Atomic Energy of Canada Limited announced it would proceed in co-operation with the Hydro-Electric Power Commission of Ontario.

The result today, just two and a half years later, is the rapidly growing structure of one of Canada's most advanced engineering projects. Located on the eastern shore of Lake Huron, 130 miles north-west of Toronto, the Douglas Point Nuclear Power Station will be powered by the heavy water moderated and cooled, natural uranium fueled reactor, known as CANDU (Canadian Deuterium Uranium). It will have a net electrical output of 200,000 kilowatts and will operate as a base load plant in the Southern Ontario network of Ontario Hydro.

The CANDU reactor is a logical development from its pilot scale predecessor NPD (Nuclear Power Demonstration), the 20,000 kilowatt nuclear electric power station at Rolphton, Ontario. The basic station cycle is similar in principle to NPD, although it differs considerably in detail.

At first it had been thought that the pressurized heavy water coolant cycle would result in a low station thermal efficiency, in the order of 25%. However, despite the limitations of the steam temperature and quality resulting from coolant conditions, the predicted station efficiency, as a result of the latest evaluations, now stands at 29.13%. This has been reached through careful design of all plant features which would affect reactor and thermal systems efficiencies.
and by developments in turbine cycle design to make more effective use of low enthalpy steam.

The Douglas Point Station consists of three buildings to house the equipment, and an administration wing. The early construction phase, which included most of the rock excavation, massive concrete construction of the circulating cooling water channels, and the erection of the reactor building shell is now complete. The reactor building dome, of ½ in. thick steel, was completed by November last year. At the beginning of March 1962, the reactor building internal construction were under way.

The footings for the turbine building and major equipment are now in place, and the service building rock excavation is well advanced. Steel erection for both the latter buildings will take place early this summer.

Contracts have been let for most of the major equipment for the station, and manufacturing is well advanced in many instances. These include, for example, the calandria, end shields, primary circulating pumps, turbine-generator, condenser, boilers, cranes and many other items to a total value of approximately

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200 Mw Nuclear power plant cut away view looking southwest

1. Calandria
2. Helium line
3. End shield
4. Primary heat transport
5. System feeders
6. Cable cart
7. Booster rods
8. Primary heat transport
9. Hot header
10. Steam generators
11. Steam drum
12. Primary heat transport system
13. Steam headers
14. Boiler feed water headers
15. Process water inlets
16. Ventilation ducts
17. Dousing tank
18. Dousing tank pipes
19. Spray tank
20. Cable trays
21. Fueling machine vault
22. Spent resin storage
23. Manway
24. Labyrinth
25. Elevator
26. Thermal shield cooling ducts
27. Blowout panel
28. Pressure wall
Calandria and dump tank

The calandria is a horizontal stepped-end stainless steel tank, 19 ft. 10 in. in diameter by 16 ft. 10½ in. long. It is connected by a moderator dump port arrangement and a transition piece to a stainless steel dump tank approximately 26 ft. by 16 ft., 8 in. by 10 ft. deep, located directly beneath it. Both are housed in the reactor vault and operate in a CO₂ atmosphere. The calandria is penetrated by 306 thin walled Zircaloy-2 calandria tubes of 4.24 in. internal diameter. These tubes are rolled into the 1½ inch thick tube sheets to form helium-tight joints. Through each calandria tube is run a 3.58 in. O.D., coolant channel which contains the fuel bundles and coolant. The calandria is suspended from structural steelwork by six water cooled Invar rods.

The design of the calandria and dump tank have involved problems in dissipation of internal heat and in obtaining helium-tight construction. The rolled joint between the calandria tube and tube sheet required a specific development program. An internal stainless steel ring, stressed in compression, maintains pressure on the tube to create a helium-tight joint. Both the design and the manufacture of the moderator dump ports presented problems as it is desirable to be able to dump the moderator as quickly as possible. The calandria is now being assembled in Montreal. The contrast for the dump tank has not yet been let.

Coolant channels

The 306 coolant channels house the fuel bundles, 12 in each channel, and direct the flow of coolant past the fuel. Each coolant channel consists of a 3.25 in. I.D. by 17 ft., 10 in. long Zircaloy-2 calandria tube attached at each end to a stainless steel end fitting. The end fittings extend through, and are supported by, the reactor end shields, and locate the coolant channels centrally within each calandria tube. An insulating CO₂ filled gap thus is formed which protects the calandria tubes from excessive heat.

Many design and manufacturing problems had to be overcome in connection with the coolant channels. The choice of the design stress of 16,000 psi for the Zircaloy pressure tubes resulted from simultaneously relating demonstrated material properties, safety requirements, neutron economy, and procurable manufacturing accuracy.

The end fittings are attached to the pressure tubes by a specially developed grooved rolled joint. This joint has shown remarkable leak tightness and strength when tested under thermal cycling and variable load conditions.

Primary coolant system

The primary coolant system comprises two loops, connected in series. Each loop includes one half of the coolant channels, a hot collector header, four heat exchanger boilers in parallel, five pumps in parallel, and a supply header from which the cooled coolant is fed to the remaining half of the coolant channels. Thus, the heavy water coolant flows in opposite directions in adjacent coolant channels. The system permits convenient grouping of the pumping and heat exchange equipment and fits in well with the boiler design.

Each boiler consists of ten 20 ft. high hairpin heat exchangers, mounted in parallel on a common set of manifolds, mounted by a single 5 ft. by 25 ft. steam drum. The heavy water passes through one-half in. diameter monel tubes welded to monel tube sheets. The design features countercflow of the feedwater and coolant in a "pre-heater" leg, and a downcomer arrangement which provides a "boiling" leg in each heat exchanger. This yields a steam temperature of 483.3F, compared with the 560F entry and 480F exit temperatures of the coolant.

The construction of the boiler units, also under way in Montreal, has required the development of special welding techniques. The areas particularly affected are the monel tube to tube-sheet joints, having a minimum ligament thickness of 0.125 in. and the tube-sheet to shell joints which require monel to steel welds.

To confirm the performance of the boiler units a prototype heat exchanger and partial steam drum will be placed on test early in the summer.

Moderator and helium system

The heavy water in the calandria serves as both moderator and reflector. A helium system, working in conjunction with the moderator circuit provides a helium cover gas in both the calandria and dump tank and forms part of the moderator level control system.

To maintain the moderator within the desired temperature range of 70F to 140F, the moderator is circulated through heat exchangers, with a small flow being channelled through a purification system. Part of the moderator flow is returned through a calandria and dump tank spray cooling system. The circulating pumps can, alternatively, pump the moderator from the dump tank into the calandria. Excess moderator in the calandria spills into the dump tank through the calandria dump ports.

The moderator is supported in the calandria by the pressure of helium in the dump tank acting on the gas-liquid interface in the dump ports. The helium pressure is provided by heavy water jet exhaustors which pump helium from the calandria to the dump tank. Helium lines, incorporating a parallel arrangement of dump valves and control valves,
connect the top of the dump tank to the top of the calandria. Moderator level can be varied to control reactivity by altering the helium bleed through the control valves. When the helium dump valves are opened, the helium pressure becomes equal at the bottom and the top of the calandria and the moderator discharges by gravity into the dump tank. This results in a rapid shutdown of the reactor.

Contracts have been placed for a number of major pieces of equipment in the moderator circuit.

End shields

The reactor end shields, 3 ft. 8 in. thick by 16 ft. 9½ in. in diameter and weighing 115 tons each, provide accurate location and support for the coolant channels in addition to shielding from the calandria vault activity. They are supported on Invar rods suspended from overhead structure and are aligned with and keyed to the calandria. The shields consist of three 12 in. thick steel slabs, with a 2½ in. water passage and a thick external steel plate on both sides. The water is circulated through a heat exchanger to remove the heat generated in the shields.

Design of the end shields has been completed, and construction is underway. Helium leak tests will be carried out on-site.

The shields present interesting problems, both in design and manufacture. The use of a carbon steel and light water shield has required control of the condition of the water. Moreover, the presence of light water has involved the question of leakage to the reactor vault area, which would downgrade the heavy water vapor collected from the atmosphere. This is accentuated by the large number of penetrations of the shields. The massive size of the shields, combined with the need for unusually close tolerances, present manufacturing and handling problems.

Fuel and fueling

The natural uranium fuel for the CANUD reactor is designed for the single pass, high burn-up fuel cycle. When it is taken out of the reactor, it will be stored permanently under water. A 19 element fuel bundle, 19½ in. long, has been chosen. The weight of the bundle will be 26 lb, of which 33 lb will be uranium dioxide. Each element comprises compacted and sintered natural UO₂ pellets sheathed in a Zircaloy-2 tube of 0.6 in. diameter by 0.015 in. wall thickness. A minimum spacing of 0.047 in. is maintained between adjacent elements.

Extensive development work, both in-pile and out-pile, has been carried out on two versions of the basic fuel bundle design. One, a wire wrapped bundle with end plates is now going into production. Another version assembled by brazing and with element spacing maintained by spacer "warps" is under development.

Amongst the many problems to be solved, have been such considerations as the possibility of sub-channel boiling, the required degree of coolant transverse mixing, the effect of coolant velocity on erosion, brazing alloys, mechanical strength, and manufacturing feasibility.

The fueling process begins with the loading of the fuel bundles by automatic transfer equipment into the 12 chamber magazine of a fueling machine. Two carriage mounted co-ordinated fueling machines, capable of being indexed to any fuel channel at either end of the reactor, can attach to the end fittings and load fuel into or accept fuel from the coolant channels. The fueling machine and end fitting design permits this to be done during normal reactor operation without interrupting the coolant flow. Thus the fuel is fed progressively through the reactor. Fueling is done in opposite directions in adjacent channels. The fact that the reactor is refueled on power not only avoids loss of power production and thermal cycling of the station, but also slightly improves reactor efficiency by increasing the burn-up of the fuel.

During reactor operation, entrance to the vaults which house the fueling machines is prohibited owing to high radiation intensity. To permit direct observation, each fueling machine vault has a shielding viewing window in the biological shielding wall.

As part of the extensive development program, a prototype fueling machine and carriage are being erected in Toronto where full-scale tests under reactor conditions, except radiation, will be made.

Turbine-generators

The turbine-generator and the associated condensing and feedwater systems are generally conventional. The turbine, rotating at 1800 rpm, has one high pressure and three low pressure cylinders. It exhausts to the condenser, which is designed for a vacuum of 29 in. of mercury. The generator produces 220,000 kilowatts of 3-phase power at 18 KV and 60 cps. To handle efficiently the relatively high volume of steam produced by the reactor (2,500,000 lb. per hour at 565 psig and 0.25% wetness fraction), the turbine is larger than a turbine of similar power for conventional steam conditions. It also provides for water removal at each expansion stage. The exhaust from the H.P. cylinder is dried and superheated by passing through a moisture separator and a live steam reheater before entering the low pressure cylinder. The regenerative feedwater system consists of five closed feedheaters and a deaerator, heated by bleed steam.

Most of the equipment for the conventional steam cycle is on order. The two largest items, the turbine-generator and the condenser are under construction.

Control system

The control system is designed to provide a high degree of automated control of the equipment and systems throughout the station. This leaves the operators free to concentrate on interpretations or on any deviations from normal. Over 1,500 sensing points throughout the station feed information into the plant con-

Simplified station flow diagram.
control equipment in the central control room.

Generally speaking, control of the station is carried out under two main systems. The regulating system relates all normal power demands to existing output and calls for reactivity changes to make them equal, providing various thermal limits for the station are not exceeded, and in particular, those limits for the individual coolant channels.

The protective system is a separate system which over-rides the regulating system. It acts either to set back the station power (at a rate of 1% of full power per second, down to 2% of full power or until the set-back signal is cleared), or to cause a trip and shut-down the station, on receipt of information that certain selected station parameters have been exceeded.

At power levels above 20% of full power, reactor power is measured in terms of $\Delta T$ (the increase in coolant temperature as it passes through the reactor). At lower power levels, it is measured by the ion chamber current. The ion chambers are located outside the calandria in a water shield tank. Their position, 7 ft. below the calandria centre line, ensures that they are exposed to thermal flux at all moderator levels which would permit the reactor to be critical.

Five means are available to control the reactivity of the reactor. They are:

- Frequency of refueling
- Absorber rods
- Booster rods (enriched uranium)
- Cadmium sulphate “poison” in moderator
- Variable moderator level

All these methods are complementary and, except for the refueling cycle, are automatically controlled and interconnected in the regulating system. The refueling cycle provides the reactor with the primary long-term control of reactivity. The absorber rods and moderator level jointly control excess reactivity over short periods of time.

Over intermediate periods, excess reactivity is controlled jointly by the absorber rods and moderator poison, augmented when necessary by reduced moderator level. Quick shutdown, or a trip, is accomplished by dumping the moderator into the dump tank. The boosters are used to over-ride Xenon poison during start-up following a short shut-down.

Instrumentation and associated circuits are triplicated in all important areas, both for the sensing and control functions. This greatly reduces the probability of a spurious fault signal being acted upon, or of a failure occurring in a control circuit.

Special features

Two special features of the Douglas Point Station deserve mention. The first is the arrangement of the reactor vault and associated area which will permit the removal and replacement of the dump tank and calandria, if this should ever become necessary. The use of a removable water-filled shielding tank, a removable slab floor and a break-out wall section make this possible.

Another feature is the provision for pressure suppression and containment of the effluent from a break in the primary coolant circuit, however remote the possibility of such a failure. The first stage is the facility for heavy water dousing of any escaping steam within the reactor vault area. Additionally, arrangements are made for channeling the effluent from a major break to a dousing area where it will be doused with light water from the standby water storage tank in the reactor building dome. The dousing serves to limit pressure build-up so that any conceivable release from the system will be contained by the building. The reactor building will withstand an internal pressure of 7.5 psig with negligible leakage. Water from the standby storage tank is available also for emergency cooling of essential heat exchangers in case of failure of the station service power.

Research and development

The research and development program in support of the CANDU reactor design has been extensive, ranging from applied nuclear, metallurgical and engineering research, to special product or systems engineering and development. Much of the development which has affected design decisions has been carried out at Chalk River or at the Development Laboratories at the Nuclear Power Plant Division of Atomic Energy of Canada Limited at Toronto. Research and development contracts have been placed with Canadian industry wherever feasible, particularly where the design of products or the establishment of new techniques or manufacturing processes have been involved.