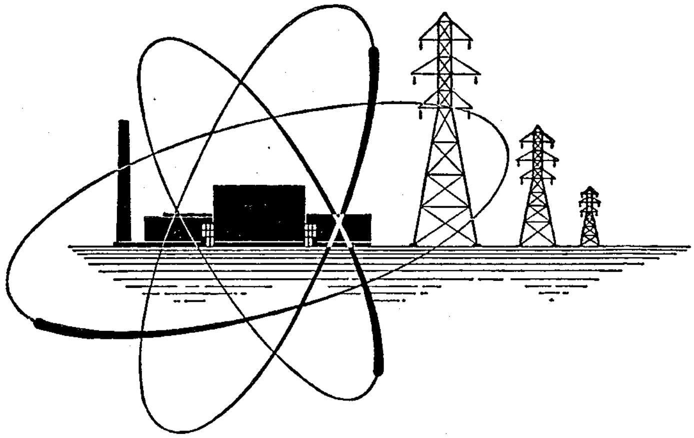


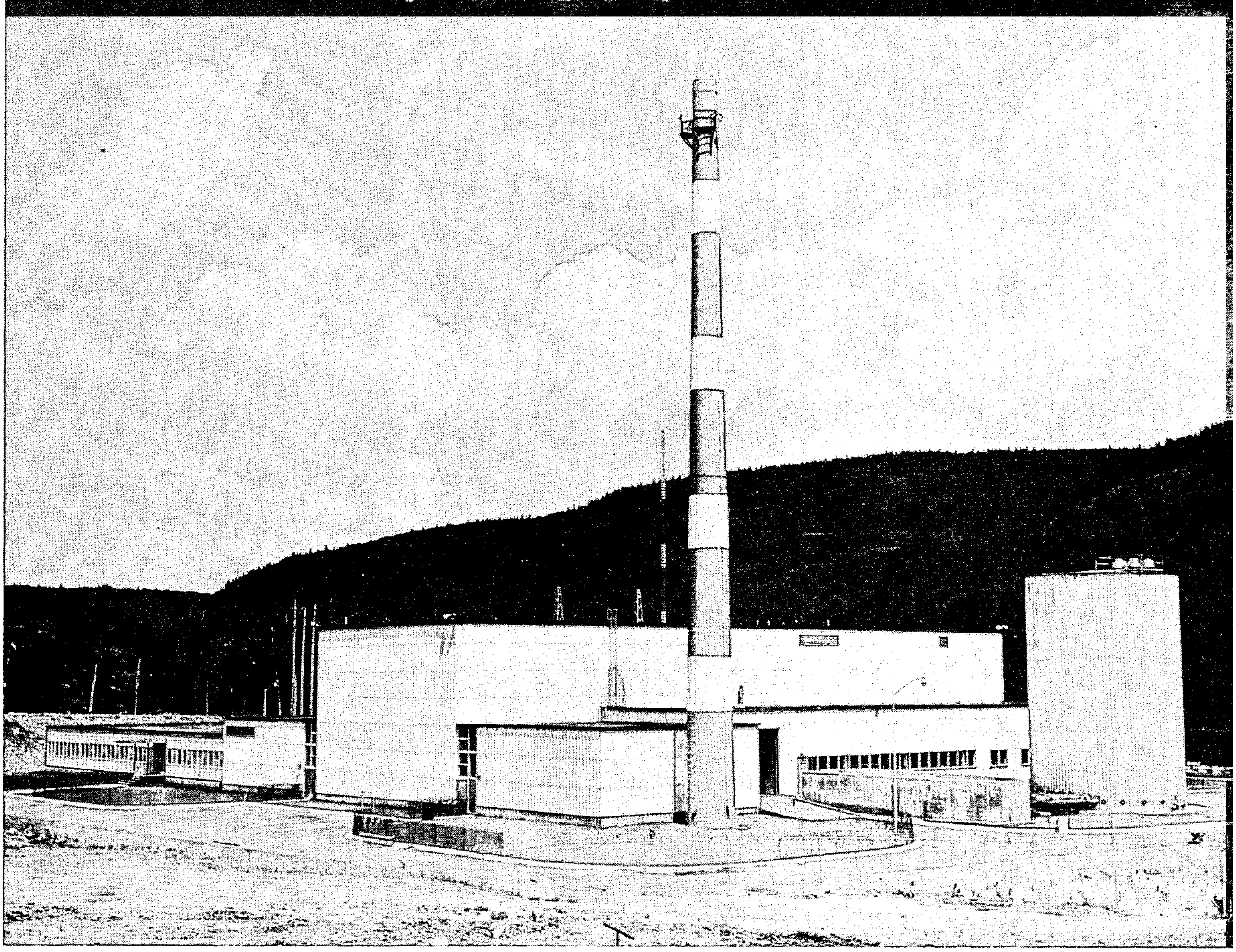
A Description of NPD

CANADA'S FIRST NUCLEAR POWER PLANT

by J. L. Olsen

An illustrated talk presented at the Seventh AECL Symposium on Atomic Energy, Chalk River, September 18, 1961

publication no. CAPD 10



Nuclear Power Demonstration

A Joint Project of:

Atomic Energy of Canada Limited
Ontario Hydro
Canadian General Electric Company Limited

An illustrated talk presented at the Seventh AECL Symposium on Atomic Energy, Chalk River, September 18, 1961

By J. L. Olsen

* * *

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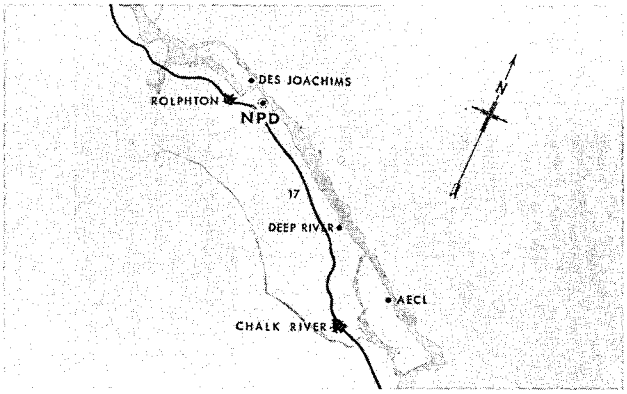
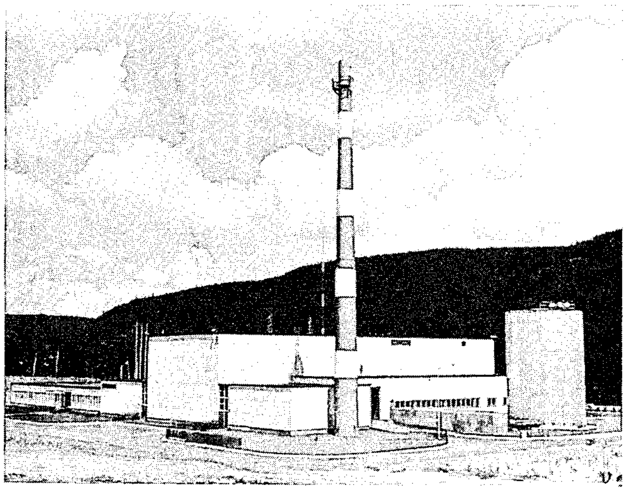
Civilian Atomic Power Department

CANADIAN GENERAL ELECTRIC COMPANY LIMITED

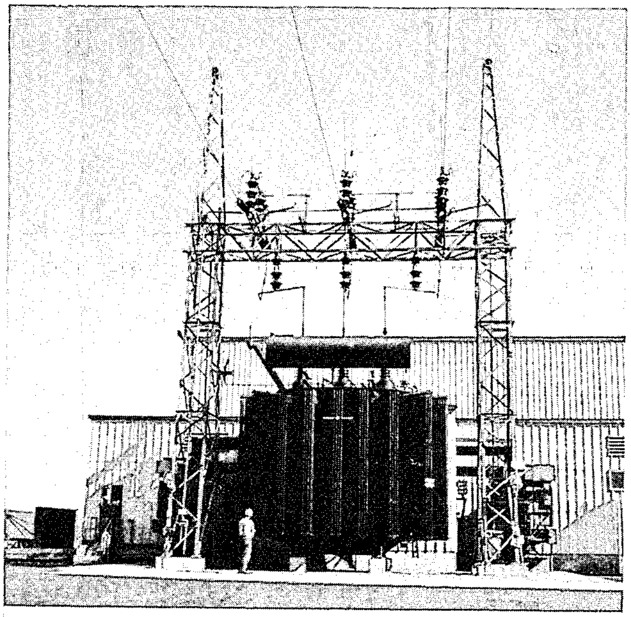
Peterborough, Ontario, Canada



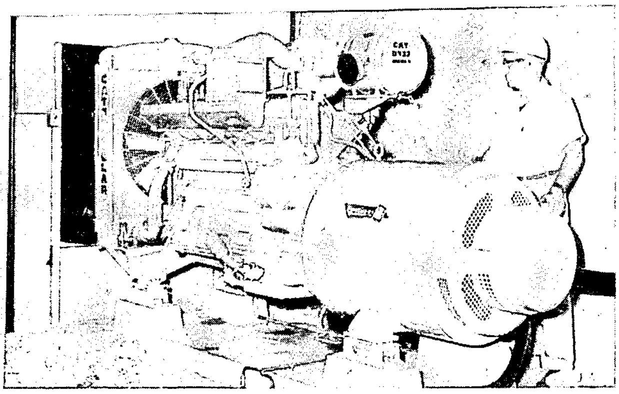
The NPD reactor project is located on the Ottawa River about 15 miles northwest of Chalk River, just to the east of No. 17 highway running toward North Bay. Approximately ½ mile away is the town of Rolphton and completing the triangle approximately ½ mile from both of these is the Hydro Plant of Des Joachims, which is part of the Ontario Hydro system.



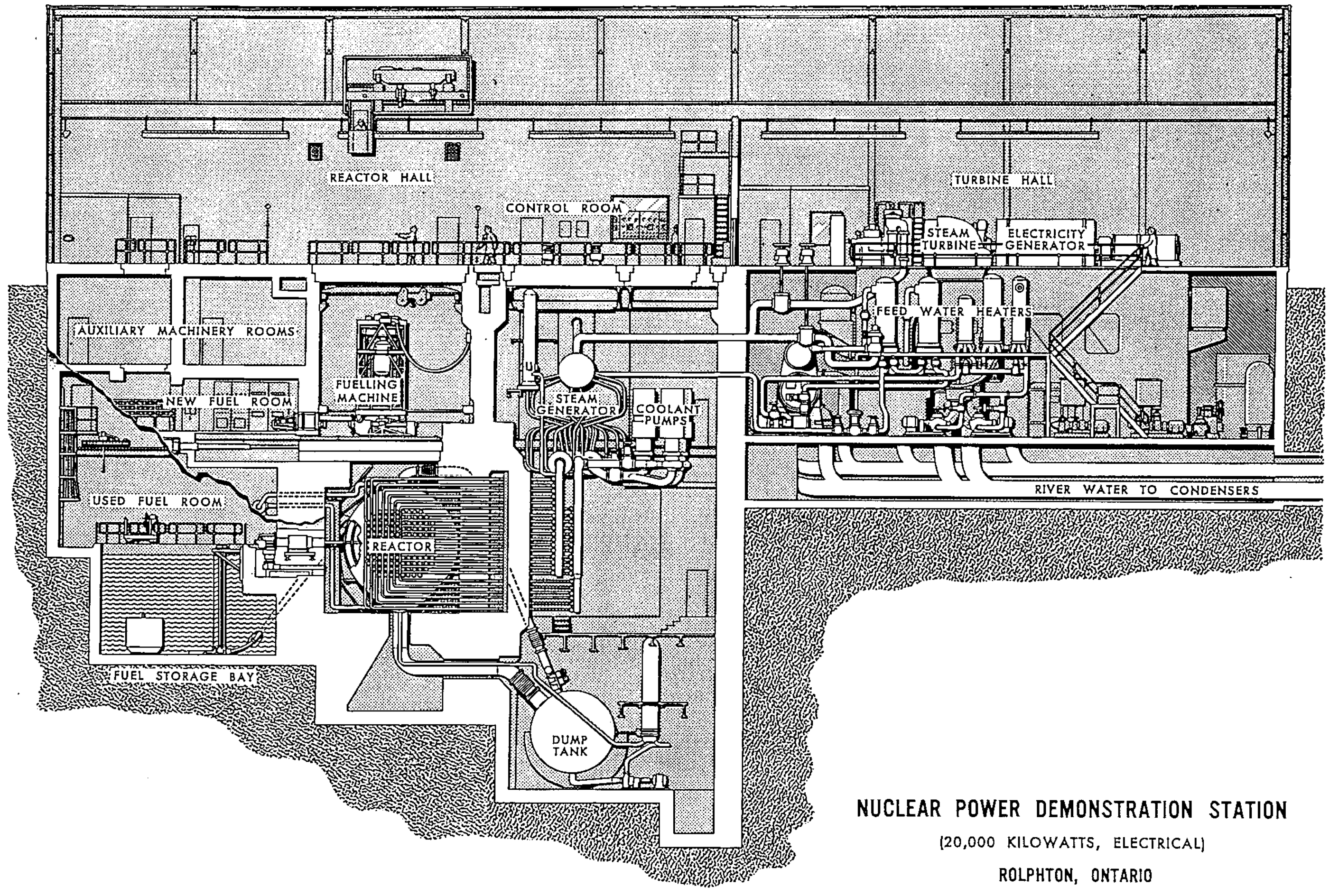
This view of the plant taken from the southwest shows the stack in the foreground, through which most of the air from the plant is exhausted. Adjacent to the stack is the pressure relief duct and next to this is the dousing water tank. The part of the building in the foreground is the maintenance and service wing, next is the reactor and turbine hall, to the left is the control wing and the administration wing is to the far left.



The letters NPD stand for Nuclear Power Demonstration, and this 20,000 kw plant is being built to demonstrate the potential of nuclear power as a competitive source of energy in the Canadian environment. This demonstration unit will supply its electricity to the 115 kv lines leading to Des Joachims which, in turn, feed into the 230 kv lines leading from the north to one of Canada's highly industrialized areas in southern Ontario. The main output transformer shown here is rated at 23,000 kva and steps up the voltage delivered from the turbine-generator from 13,800 volts to 115,000 volts. The station service transformers are located on either side of the main transformer.



Just inside the door from the main transformer, provision has been made for standby power. This can be obtained either from the diesel-driven generator or from the battery room.

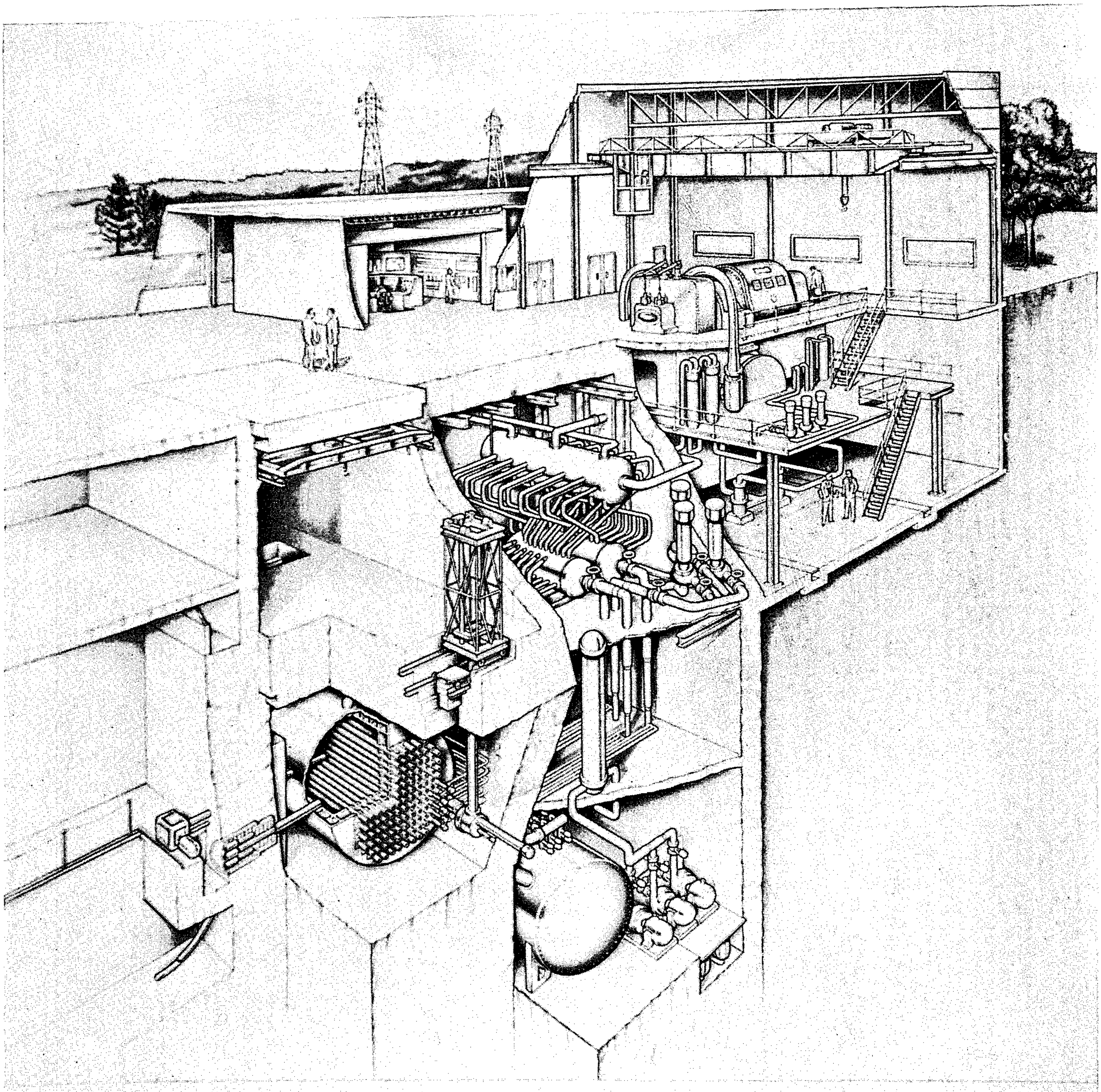


NUCLEAR POWER DEMONSTRATION STATION

(20,000 KILOWATTS, ELECTRICAL)

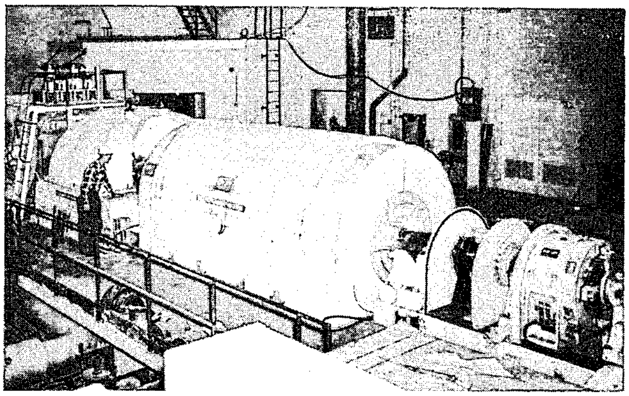
ROLPHTON, ONTARIO

A cross section of the building gives an indication of the layout. At ground level, the main part of the building which is 180 feet long and 60 feet wide, is divided into the turbine hall and the reactor hall. The turbine-generator is located at ground level with the condenser, feedwater heaters, feedwater pumps and water purification system located directly below the turbine hall. The steam generator and main coolant pumps are located behind a shielding wall and under the reactor hall. On the same level behind another shielding wall is the fuelling machine carriage. The reactor vault contains the core of the nuclear system which is surrounded by a biological shield equivalent to 4½ feet of heavy concrete. Two retractable shielding gates can be pulled back to open two slots, one at either end of the reactor core, thus permitting the fuelling machine heads to be lowered from the carriage into the reactor vault. The area within the reactor vault cannot be entered at any time after start-up. The area immediately outside the shutdown shielding can only be entered under shutdown conditions. An additional 2½ feet of operating shield separates the areas that are accessible during operation from the high radiation centre. The new fuel room is shown to the left of the illustration and below this is the used fuel room and the fuel storage bay where the spent fuel from the reactor core can be ejected for storage. The moderator dump tank, which holds the heavy water from the reactor core during shutdown, is located at the other side of the core at the lowest part of the building. Between the dump tank area and the steam generator area, space has been left for headers and feeders connecting the reactor core to the steam generator. The entire station is remotely controlled from a central control room located adjacent to the reactor and turbine halls.



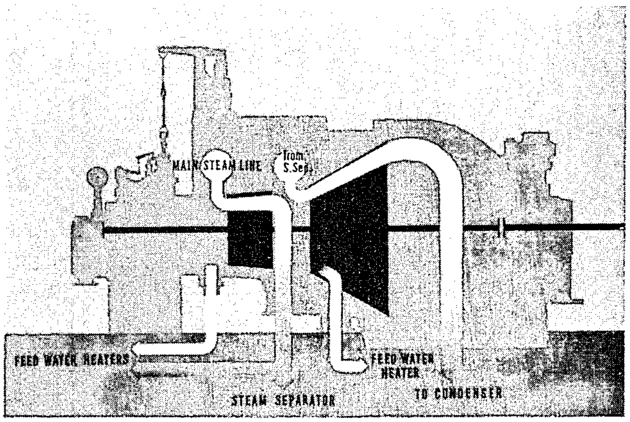
NPD (NUCLEAR POWER DEMONSTRATION)

This cut-away model of the plant shows the location of the generator, the turbine, condenser and feedwater equipment, heat exchanger and main coolant pump, the header room, the fuelling system and finally the control room.

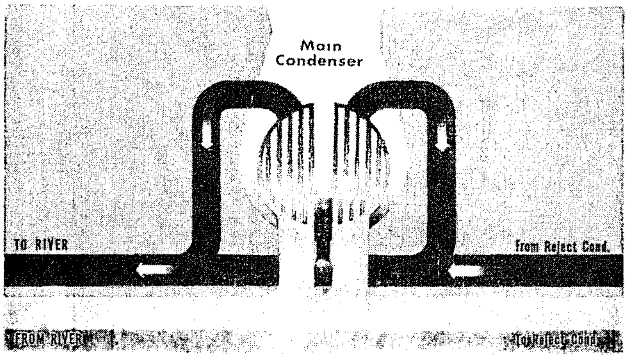


The alternating current generator that feeds the main transformer is of two-pole synchronous type with stationary armature and rotating field. It is rated at 25,882 kva and generates power at 13,800 volts, 3 phase, 60 cycle.

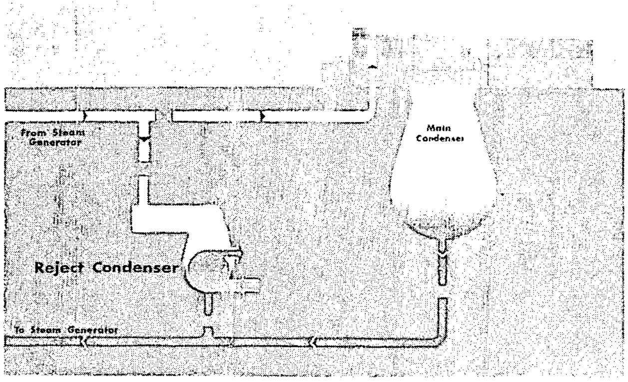
The turbine driving the generator is a single flow impulse type with single cylinder and separators with a maximum capacity of 22,000 kw and maximum rating of 20,000 kw. Dry and saturated steam at 400 psi and 450°F is admitted through two 8″ steam pipes to two combined isolating and emergency stop valves. The steam passes into the steam chest which is formed integrally with the top half of the cylinder casing, through four governing valves operated from the turbine governing system. These governing valves operate in sequence and each controls admission to one quadrant of the first turbine stage. This picture was taken during installation.



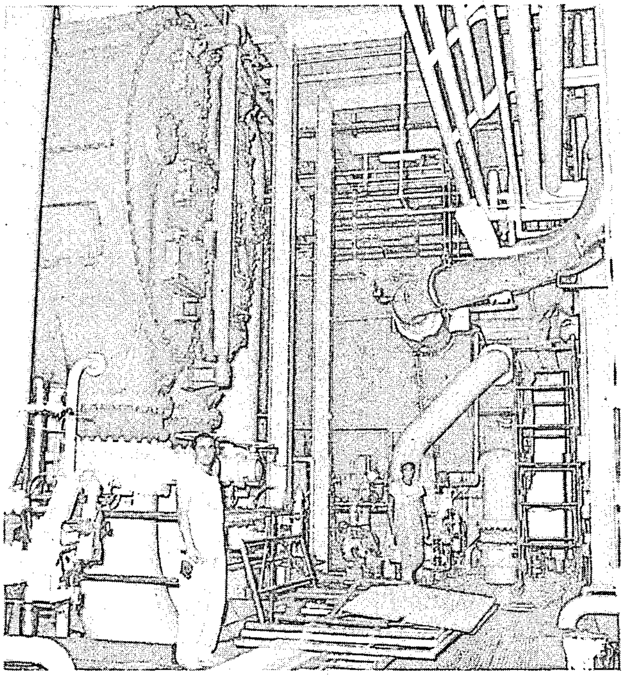
The main flow of the steam path is through the first stages of the turbine before it is removed and taken to the centrifugal steam drier, where about 95% of the moisture that has been formed in expansion is removed, and then the steam is re-admitted to the turbine and expanded to the condenser through the final seven stages. Some of the initial steam as well as the steam from the 6th, 8th, and 12th stages is extracted for the high and low pressure feed water heaters.



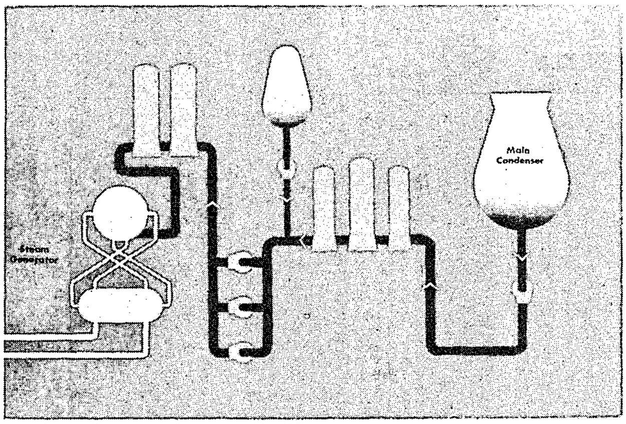
The main condenser, which is located just below the turbine, is bolted to the turbine exhaust flanges, and supported on springs. The steam flows toward the centre of the condenser where air take-off is provided. A maximum of 18,000 igpm of circulating river water flows through the condenser tubes in two passes, entering through two 30″ diameter connections and leaving through two 24″ connections. The condenser is constructed so that half of it can be isolated when the plant is on reduced load, thus permitting cleaning of the tubes in the other half. Condensate from the main condenser is extracted by one of two full capacity condensate pumps.



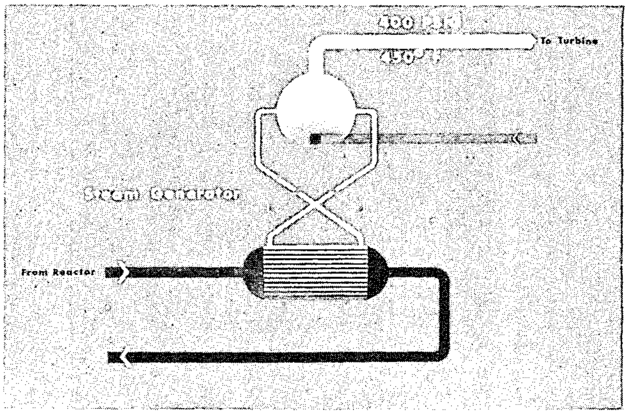
The reject condenser is located near the main condenser and has been installed to permit the reactor to continue operating on reduced load when it is necessary to shut the turbine system down. This unit is a two pass surface condenser, using 3500 igpm of circulating water.



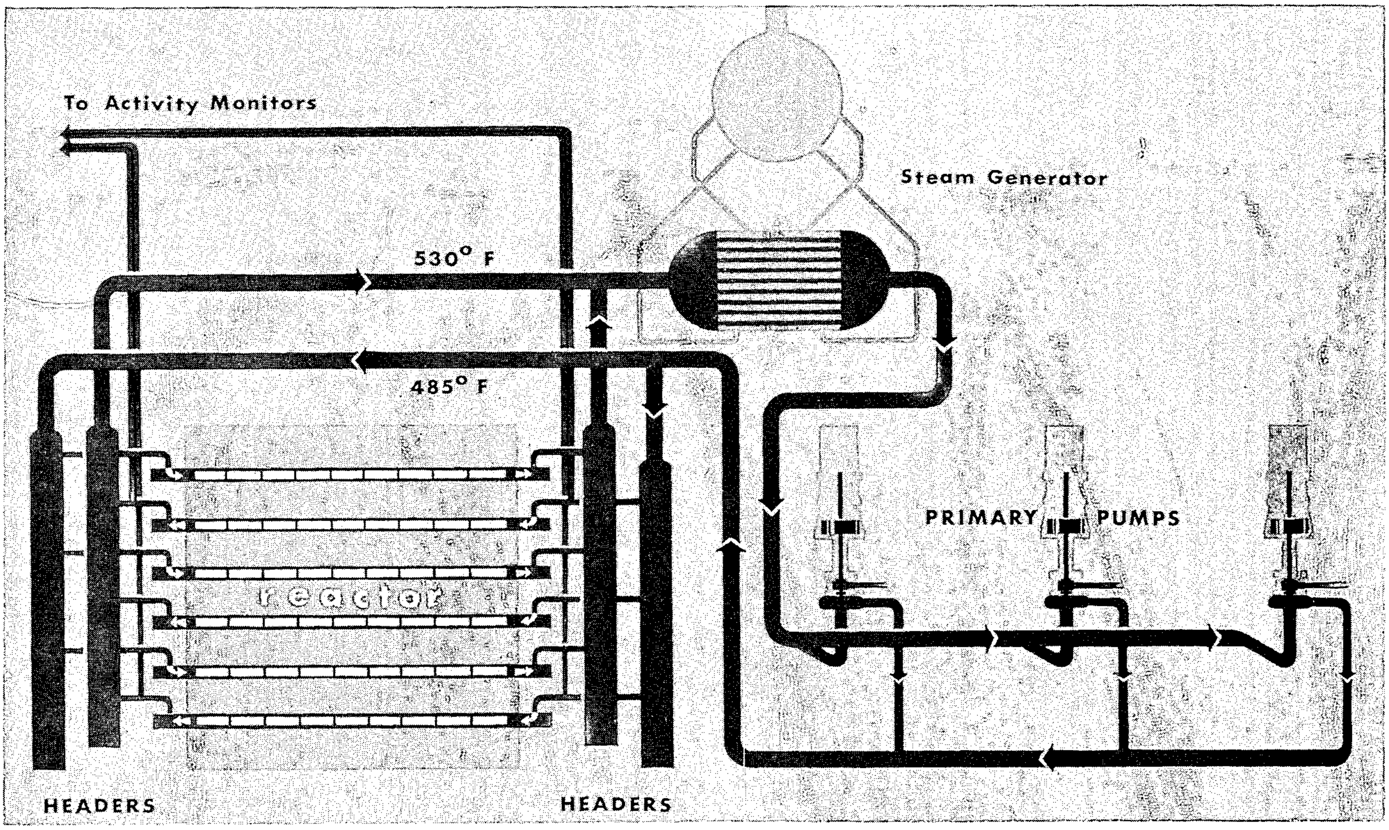
The piping connection to the reject condenser runs from the main steam piping ahead of the turbine isolating valves, through pressure reducing valves, through a 32″ de-superheating line and then to the reject condenser, shown in the background. In the left foreground is the main condenser.



Condensate is pumped through a drain flash condenser followed by a low pressure feed-water heater and a glands condenser, then to the suction manifold of three 50% capacity boiler feed pumps. These pumps deliver the water through two high pressure feed-water heaters to the steam generator.

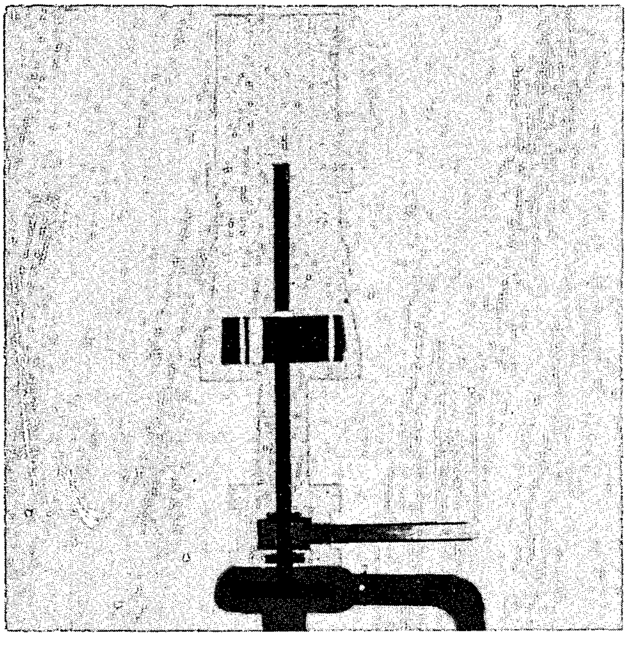


The steam generator consists of a shell and tube heat exchanger and a steam drum, with the two connected by risers and downcomers. The heavy water coolant or heat transfer medium coming from the reactor core flows through the tubes of the heat exchanger transferring its heat through the tubes to produce steam in the shell. This steam promotes natural circulation up the risers and into the steam drum where cyclone separators take out the moisture. Water returns down the downcomers to complete the natural circulation circuit. The dry and saturated steam at 400 psi and 450°F, is then piped to the turbine.

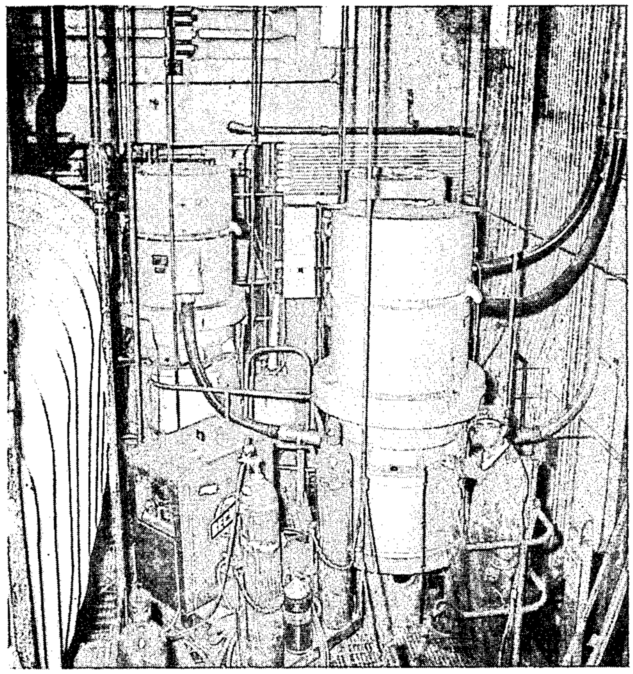


The heavy water heat transfer medium, or coolant, leaves the heat exchanger and flows to the inlet manifold of three primary pumps, two of which pump it back to the reactor through two main inlet headers, each of which is connected to 66 feeders which in turn are connected to individual pressure tubes inside the reactor core. There are 132 pressure tubes in the reactor and the coolant flows in opposite directions in adjacent tubes. The heavy water enters the reactor core at about 485°F and as it travels over the fuel bundles it picks up sufficient heat to leave the core at about 530°F. The entire heavy water system is maintained at over 1,000 psi, therefore there is no boiling in this part of the system

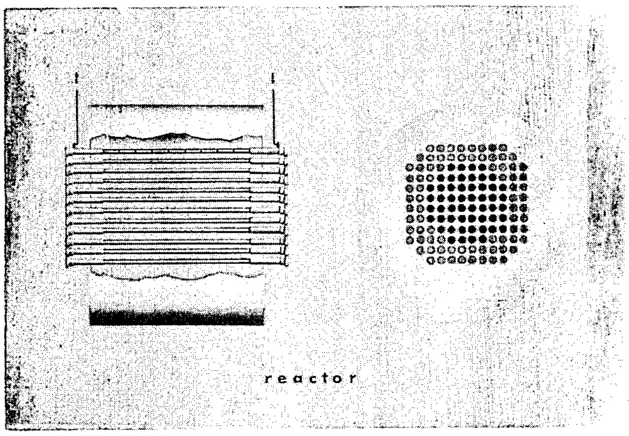
A continuous sample of coolant is taken from each outlet header and monitored for radio-activity. In addition, the inlet flow and outlet temperature are continuously checked. The reactor will automatically shutdown if the activity becomes too high or if there is a decrease in flow with an increase in temperature. The primary coolant pumps are vertical, single stage centrifugal pumps designed to give 5,000 gal/min each so that the total requirement of 10,000 gal/min can be obtained from two pumps. A third identical unit is available for standby duty.



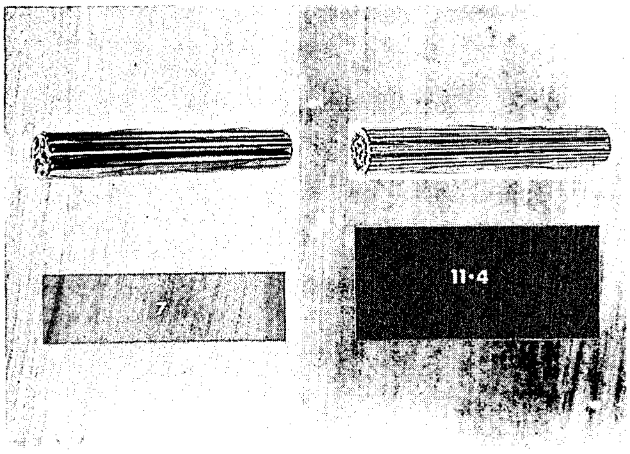
Each primary pump has two sets of shaft seals to restrict leakage of heavy water. Provision is made for collecting the leakage entering the space between the seals. A flywheel located on the pump shaft is designed to provide sufficient inertia to turn the pump after power has failed until adequate reactor cooling can be obtained by natural convection circulation.



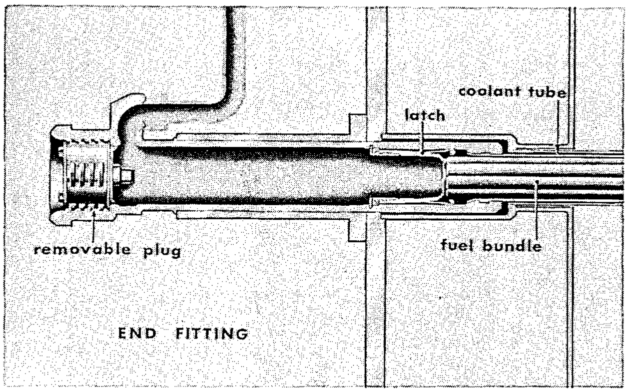
This photograph, taken during installation, shows the three primary coolant pumps.



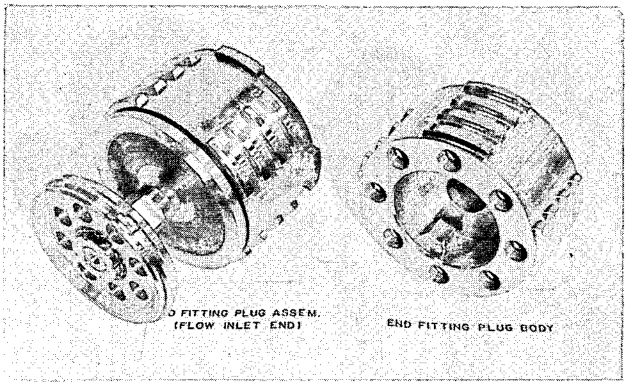
This illustration of the reactor shows the arrangement of pressure tubes or coolant tubes. These tubes, made of zircaloy, bridge the gap between the inlet and outlet feeders. Each coolant tube is loaded with 9 fuel bundles each of which contains about 33 lbs. of uranium dioxide. The total charge consists of 1,188 bundles and the total weight of fuel in a loaded core is about 20 tons of uranium oxide. The central channels in the core see a greater concentration of free neutrons and therefore produce more power than the outside channels. For this reason 19 element fuel bundles with a larger surface area are used in the central regions of the core, whereas 7 element bundles with the same overall diameter but with a smaller surface area are used in the outer regions. Under normal operating conditions it would take almost three years for the fuel bundles to move through the central regions of the core, whereas it would take approximately 9 years for a bundle to move through a channel in the outer regions to produce a similar burn-up. The rate of coolant flow through the various channels is controlled by orifices so that the temperature rise across each channel is approximately the same. The extension of the individual tubes beyond the core is known as the end fitting.



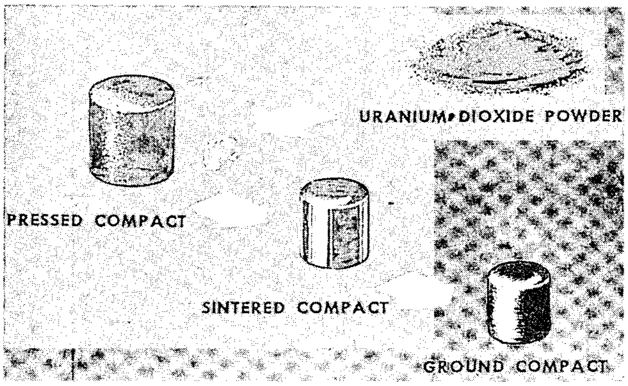
This illustration shows the comparison of the relative surface areas of the seven and nineteen element fuel bundles. Both fuel bundles have the same outside diameter.



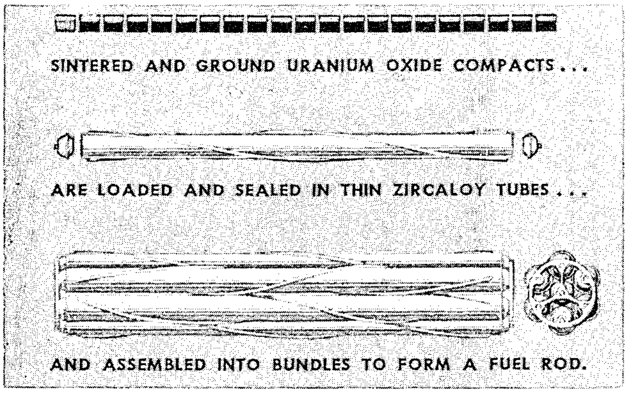
A more detailed illustration of the end fittings shows that the feeder pipes are connected to the sides of the pressure tube channels to allow for the insertion of new fuel and similarly for the extraction of spent fuel. The zircaloy coolant tube is expanded into grooves in the cast steel end fitting to produce a very satisfactory leak-tight joint. The fuel bundles are held inside the reactor core by a small latch mechanism which holds them against the flow of the coolant. Removable end plugs seal the end of the tubes of end fittings, to maintain coolant pressure.



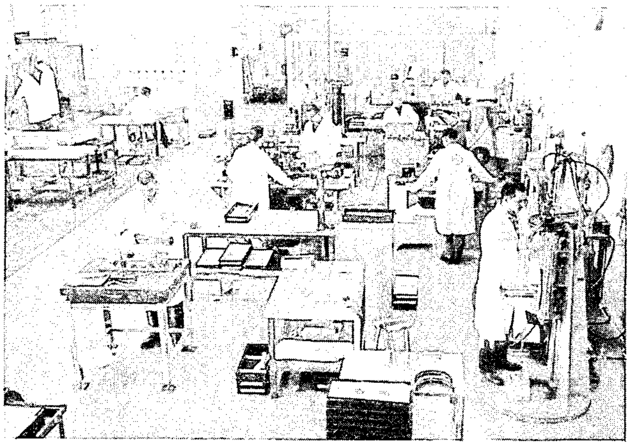
This photograph shows two of the removable end plugs, the one on the left with the orifice attached is for the coolant inlet end or fuel discharge end, whereas the one on the right is for the coolant outlet end of the channel.



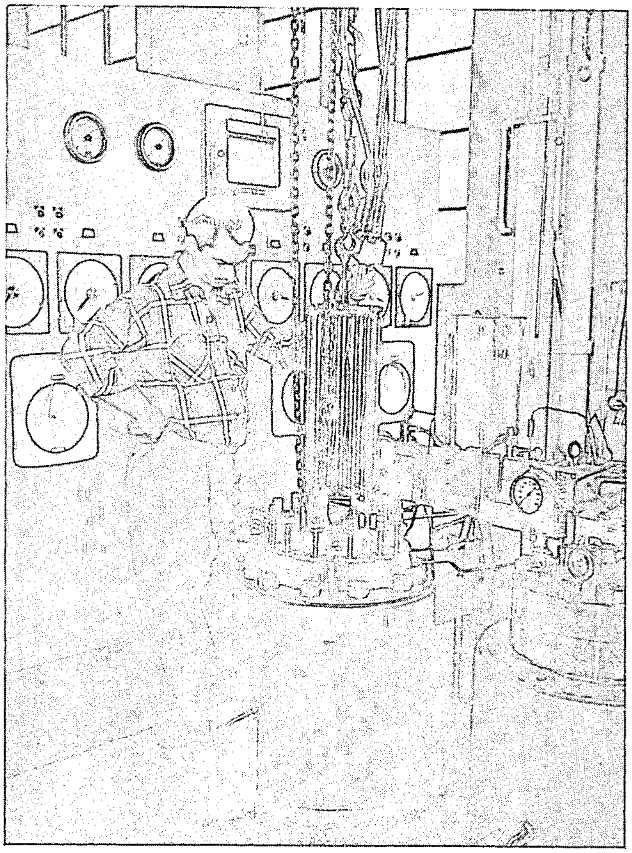
The fuel for this reactor is natural uranium dioxide clad with zircaloy. The uranium dioxide powder is pressed into a pellet, then sintered to obtain high density and finally ground to the specified size.



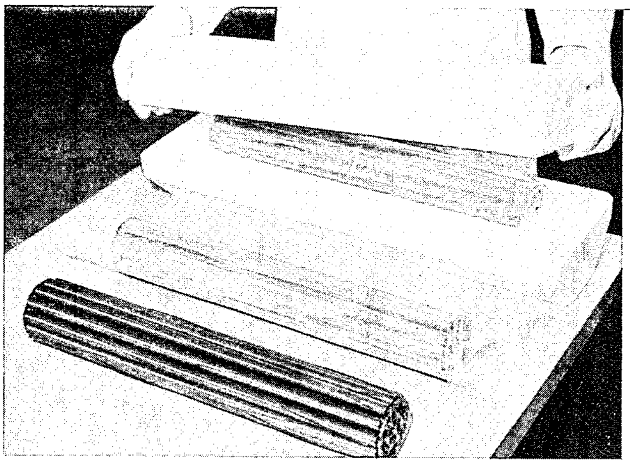
The ground pellets are loaded into carefully sized and inspected zircaloy tubes, capped at one end by an automatic welding process. After the tube has been loaded, the air is purged from it and an inert gas is forced in. The second cap is then automatically welded into position to complete an individual element which is 19½" long. Zircaloy wire is next spotwelded in a helical path on the surface of the tube. To form a bundle, 7 one inch diameter elements or 19 ½ inch diameter elements are held together by end plates. Within the bundle the elements are separated by the zircaloy wire which forces the coolant to flow in a helical path between the individual tubes as well as around the outside of the bundle after it has been inserted into the coolant tube.



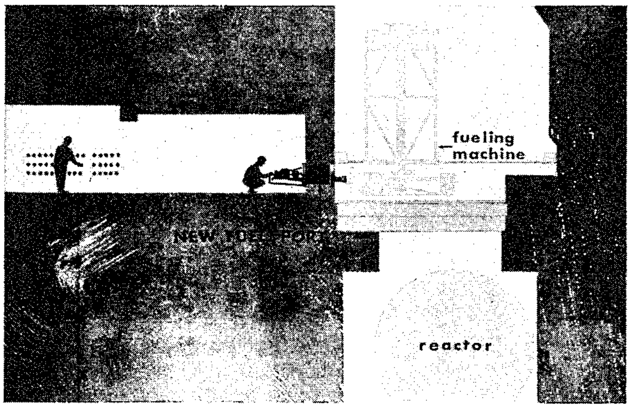
It is very important to keep foreign material away from the uranium oxide fuel and therefore it is fabricated under very clean conditions. Both the uranium and the tubing is very carefully inspected by means of dye penetrant crack detection tests and vacuum bubble tests.



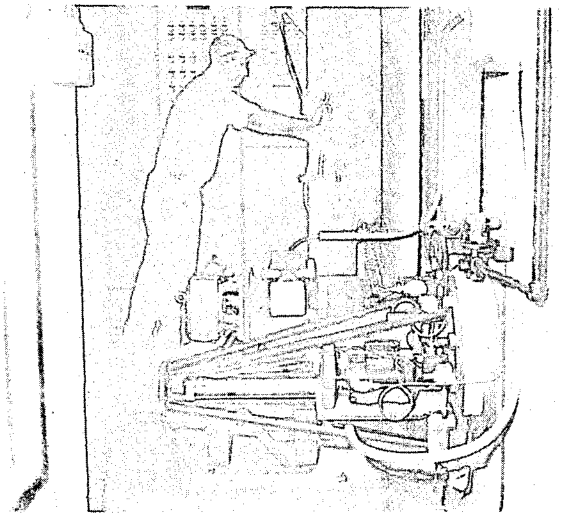
The completed bundles are finally inserted into an autoclave both as a final inspection and also to produce a protective oxide coating.



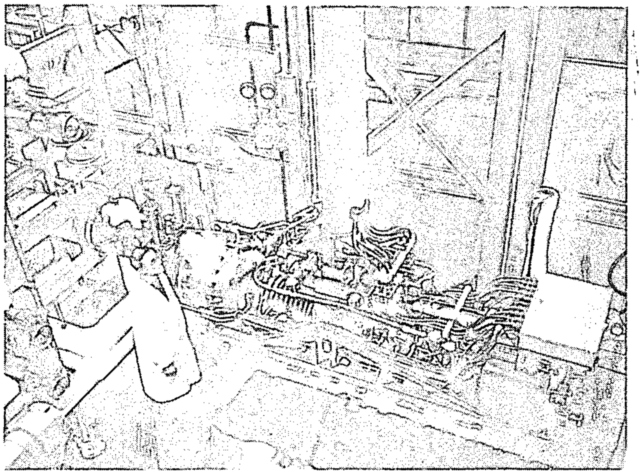
The bundles are then sealed in plastic bags and packed into light-weight plastic containers. They are shipped to the site in these containers and enter the NPD plant through the trucking area, then by elevator down to the storage area.



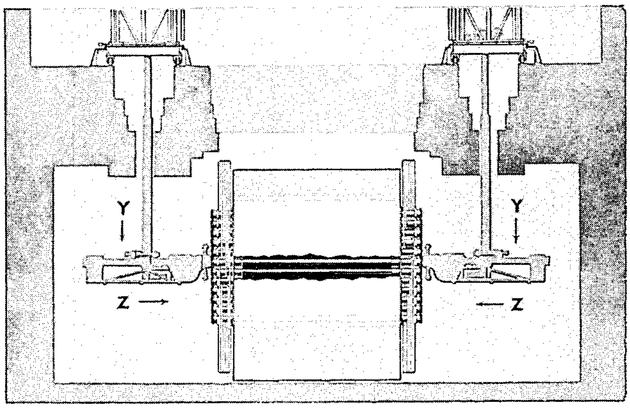
As required, individual fuel bundles move from the storage area and are inserted into the new fuel port. . The new fuel ports provide a means of transporting fuel bundles through the shielding wall between the fuel storage area, which can be entered during reactor operation, and the fuelling machine area which cannot be entered during reactor operation. The ports are designed to provide the same shielding effect as the shielding wall itself.



Five fuel bundles can be loaded into each new fuel port and an instrument panel located nearby has a built-in memory system which allows the operator in the control room to determine which of the five chambers in the fuel port contains new fuel bundles.

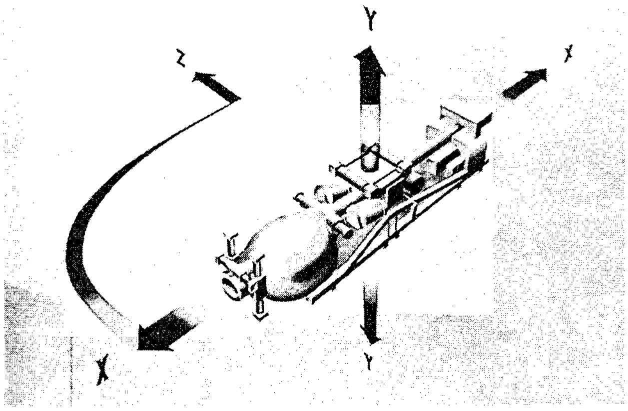


The fuelling machine has been one of the more complex mechanisms designed and built for this reactor. This picture shows one of the fuelling machine heads under test in the Development Laboratory of Canadian General Electric Company Limited in Peterborough, Canada.

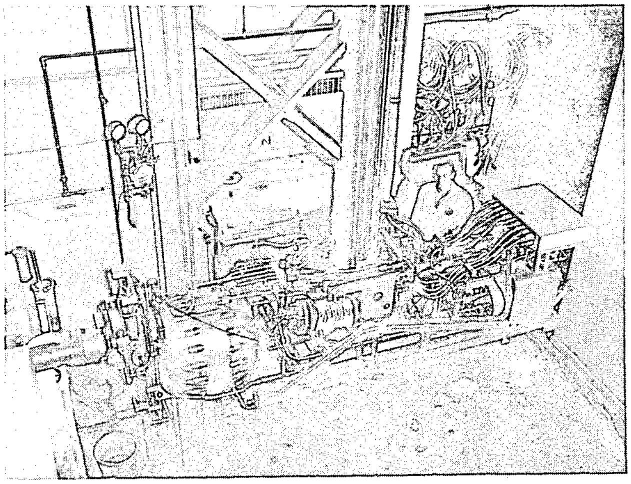


The fuelling machine provides a means of: (a) remotely accepting new fuel bundles from the new fuel port; (b) transferring the bundles to either reactor face; (c) removing the end plugs from the end fittings without loss of heavy water or pressure; (d) inserting a new fuel bundle in one end thus pushing ten bundles along the channel until a spent fuel bundle is accepted by a machine at the other end; (e) again remotely re-sealing the system with the end plugs; and (f) finally transferring the spent fuel bundles to the chute which allows them to drop into the spent fuel bay. The new fuel port is located just under the fuelling machine carriage. In the retracted position the head must be rotated 90° to pass through the slot. After is has been lowered through the slot the head can be rotated around the Y axis to line up with a specific end fitting. By movement in the Z direction the fuelling machine head is brought into position to lock on to the end fitting.

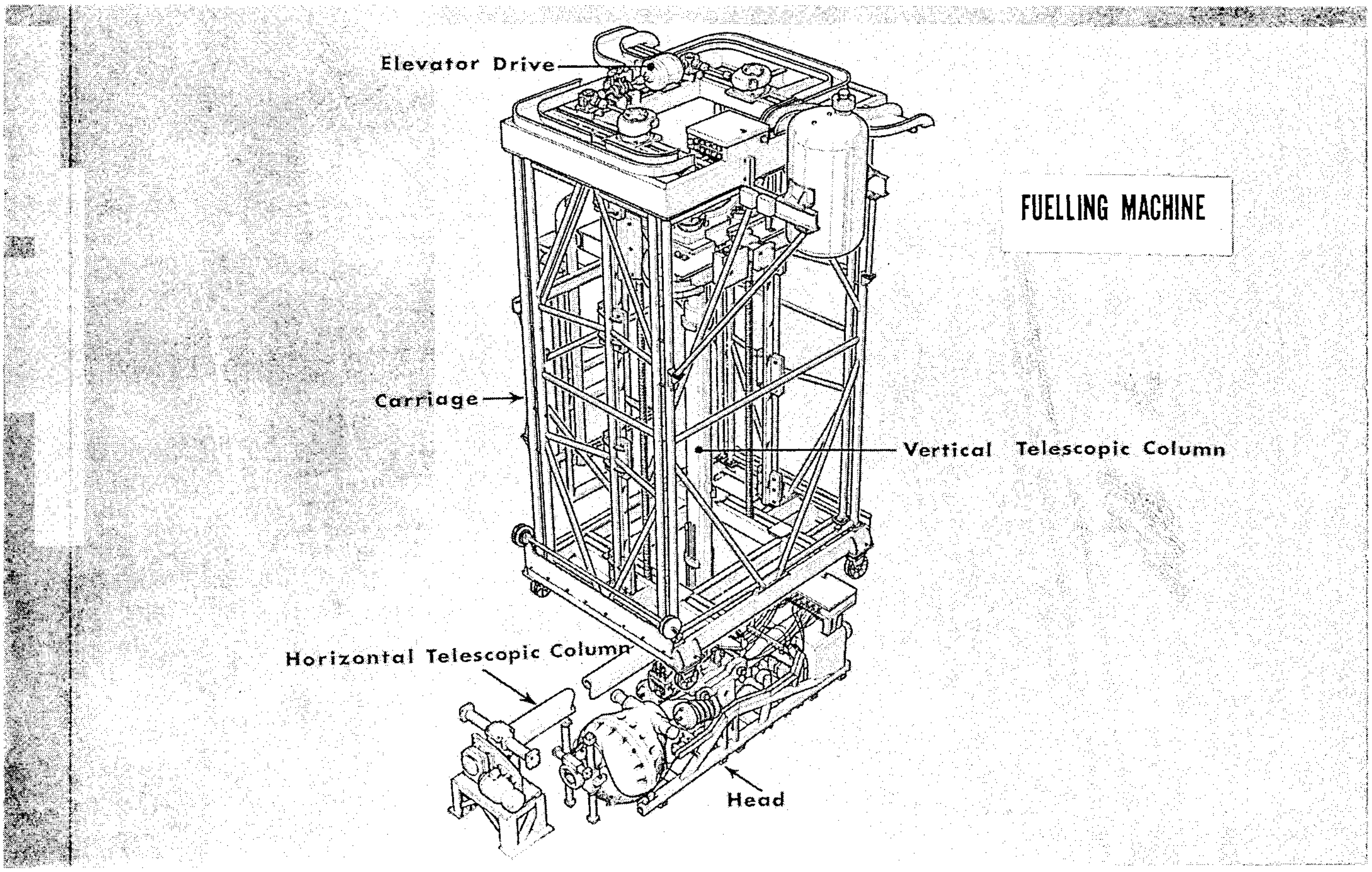
Two identical machines are required, one at either end of the reactor core. During the loading sequence one machine acts as the new fuel carrier while the other acts as the spent fuel receiver. Either machine can perform either role as determined by the direction of coolant flow in the specific channel in which the fuelling operation is to be carried out.



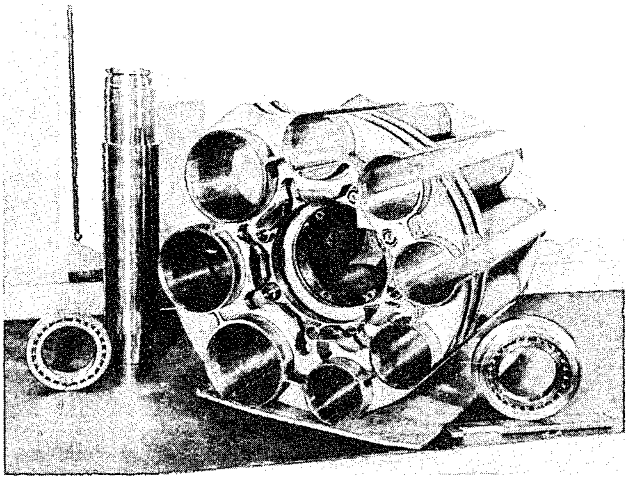
The horizontal and vertical movements are referred to as X and Y movements respectively; movement in the direction parallel to the reactor centre line is referred to the Z movement. The machine is capable of moving in the direction of all three axes, as well as being rotated around the Y axis. A drive rotates the fuelling machine head around the Y axis into a position where the snout of the head is about ½ inch away from the end of the end fittings. Fine homing in the Z direction is then carried out at the rate of about ½ inch per minute.



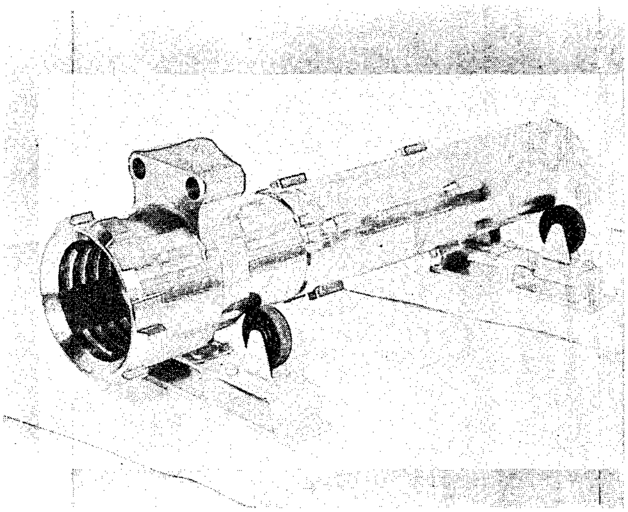
Through the use of a constant support hanger, there is also a provision for slight vertical movement when the fuelling machine has been attached to an end fitting.


FUELLING MACHINE

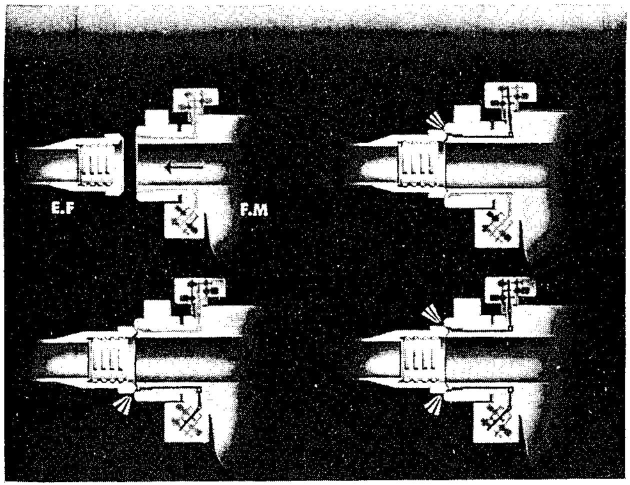
Each fuelling machine consists of a carriage mechanism and a head mechanism. The carriage assembly supports the head by means of a vertical telescopic column. Vertical motion of the head is obtained first through an elevator drive to position it just below the shielding gate, and then through the telescopic column. Each carriage can also move along the horizontal axis, parallel to the reactor face, and this movement is produced by the horizontal telescopic column. Both the horizontal and vertical telescopic columns are provided with coarse and fine drives. The mechanism at the end of the fuelling machine head is the snout drive mechanism which rotates the locking nut after the fuelling machine has been brought into proper contact with the end fitting.



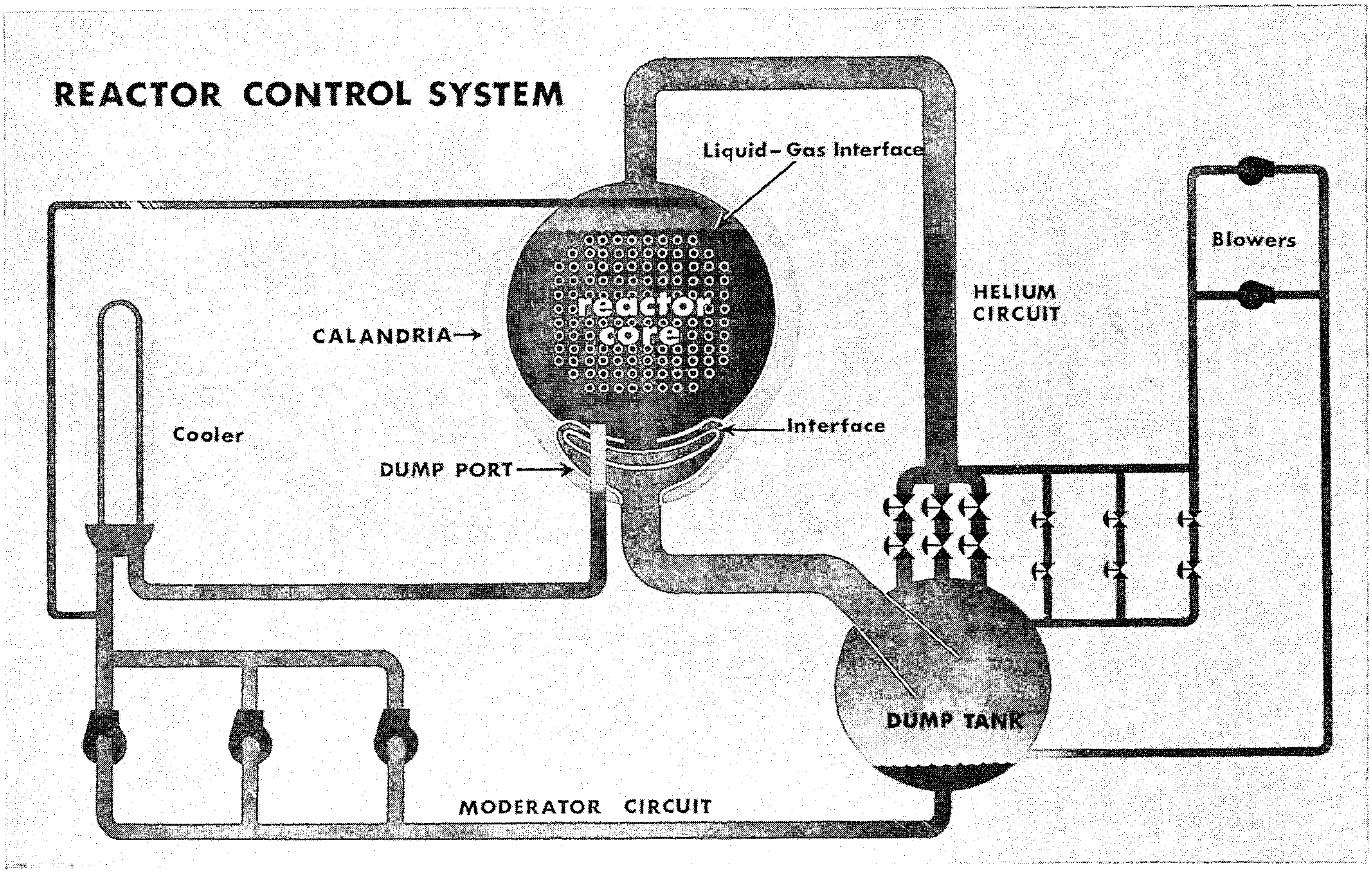
The fuelling machine housing contains a magazine with eight chambers around its periphery. Five of these chambers are for fuel bundles, two of them are for end plugs from the end fittings, and the eighth chamber is a working chamber through which the fuel loading tube is inserted.



The end fittings, one on each end of the 132 coolant tubes as well as on the new fuel and spent fuel ports, are designed as mating parts to the fuelling machine snout.

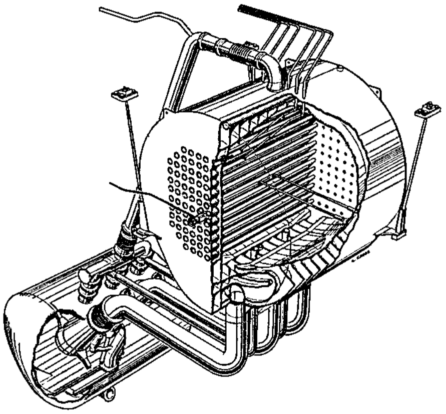


When the fuelling machine has been properly aligned with a specific coolant tube in the X and Y direction, it is moved toward the end fitting at a rate of about ½ inch per minute, and final alignment between the fuelling machine snout and the end fitting is achieved through four sensing fingers spaced at 90° intervals on the snout. These sensing fingers contact the tapered surface of the end fitting as the head moves forward. If, for example, the top finger makes contact first a signal will be relayed to the controls asking for an upward correction along the Y axis. If there is a slight over correction the bottom finger will then make contact requesting a slight counter adjustment. Similar adjustments take place along the X axis. When all four fingers have made contact, the fuelling machine is in position and the locking nut can move forward onto the end fitting in order to clamp the two together. An O-ring seal is thus energized to prevent any escape of heavy water at 1,000 psi pressure. The fuelling machines are then in position to perform the loading operation.

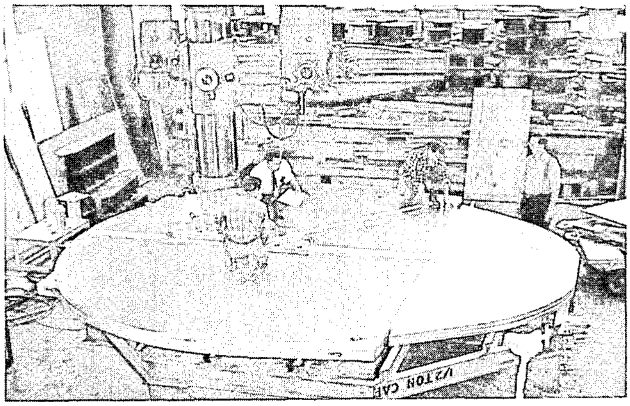


The NPD control system is unique as far as power reactors are concerned. Since a very efficient liquid moderator is used control of power output can be achieved through regulation of: the amount of moderator in the core; and the density or temperature of the moderator. This in turn regulates the number of effective neutrons available to bombard the uranium atoms in the fuel. The double-walled aluminum vessel surrounding the coolant tubes is called the calandria. This vessel has its own honeycomb arrangement of 132 aluminum tubes through which the zircaloy coolant tubes are inserted. This means that the heavy water moderator system is completely separated from the heavy water coolant system with the moderator occupying the space on the shell side and the coolant occupying the space on the tube side. Ordinary water is located between the inner and outer walls to act as a reflector. The heavy water moderator can be controlled at any desired level within the inner wall of the calandria. At the bottom of the vessel is a chicken feeder type of dump port designed so that a head of heavy water can be supported in the calandria by a differential in gas pressure between the liquid gas interface in the dump port and the liquid gas interface in the calandria proper. Two helium blowers maintain the gas pressure differential required to support the necessary height of heavy water in the reactor.

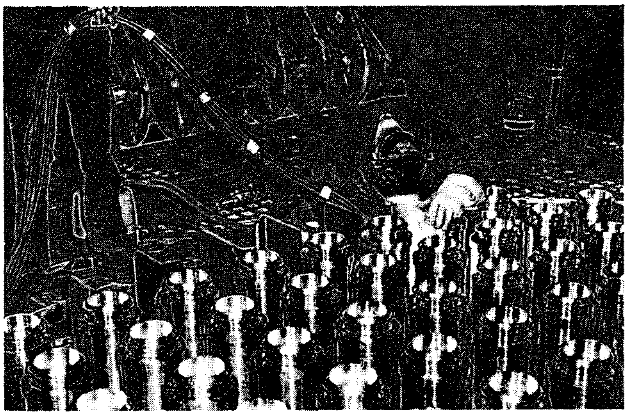
Three 24″ diameter pipes connect the dump port of the calandria with the dump tank which stores the heavy water moderator when emergency shutdown is called for. The helium piping acts as a vent to equalize the gas pressure between the top of the calandria and the dump port area as soon as the fail safe valves are opened or the helium blowers are shutdown. The dump tank is also connected to the manifold of three heavy water pumps which can be used to fill the calandria, to provide spray cooling for the top coolant tubes, and also to pump the moderator through the cooler to provide control of temperature between 120°F and 180°F. This provides a reactivity adjustment of about 7 mk. Heat is generated in the moderator by: (a) radiation absorption; (b) neutron collision; and (c) heat transfer from the primary coolant system in the reactor core. The normal cooling load imposed on the moderator heat exchanger is about 7.9% of the useful reactor thermal output of 81,000 kw.



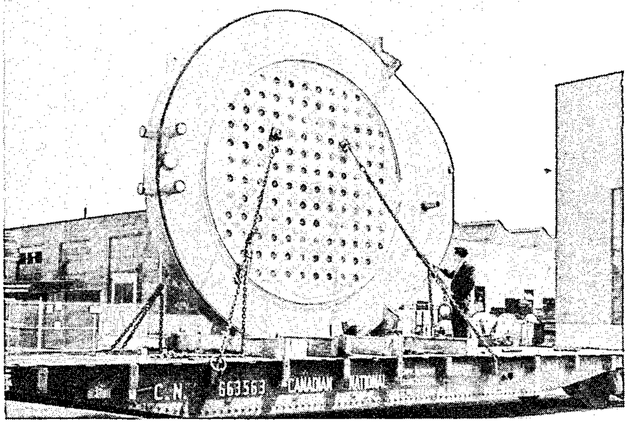
This illustration shows a cut-a-way of the entire reactor core including the calandria. Many interesting design and manufacturing problems were encountered during the fabrication of the calandria and dump tank. Both of these vessels are made of Alcan C54S aluminum alloy. The calandria is about 17 ft. in diameter and about 15 feet long. The inner side wall is ¼ in. thick and the inner end walls are ½ inch thick. The outer side wall is ½ in. thick and the outer end walls are about 2 inches thick. The aluminum calandria tubes are 4 in. in diameter and .054 in. in wall thickness.



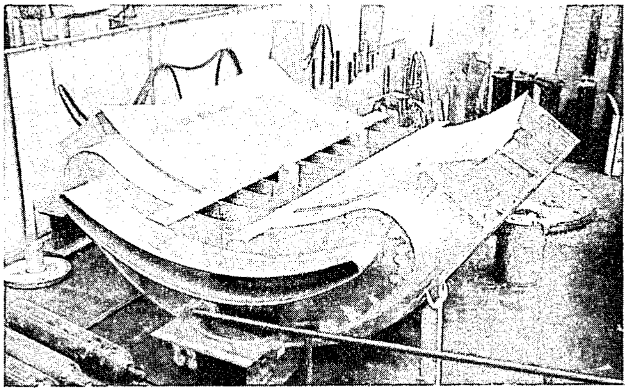
The fabrication of the calandria started by welding together three plates which were then cut to shape for the end walls. The 132 holes for the fuel sites were then pilot drilled and bored.



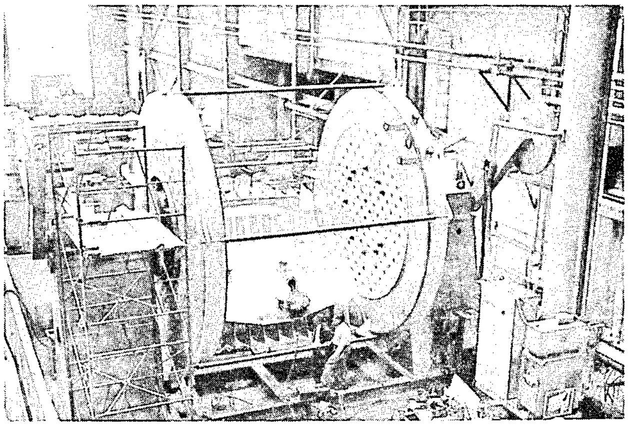
Short reflector end tubes were welded into the holes and after complete inspection, including radiographing of the fillet welds, a prepared inner end plate was welded to the other end of the reflector tubes.



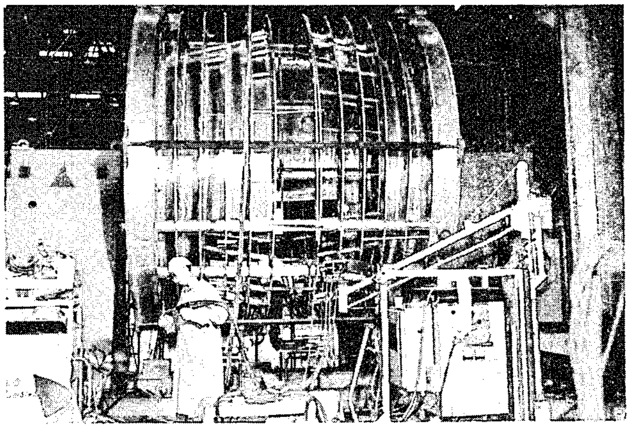
A wrapper plate was next welded around this honeycomb assembly to produce an integral end wall. The procedure was the same for both end walls.



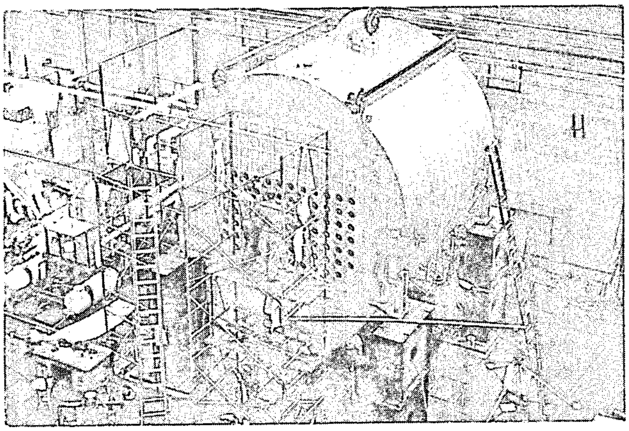
The moderator dump port was welded as a separate assembly.



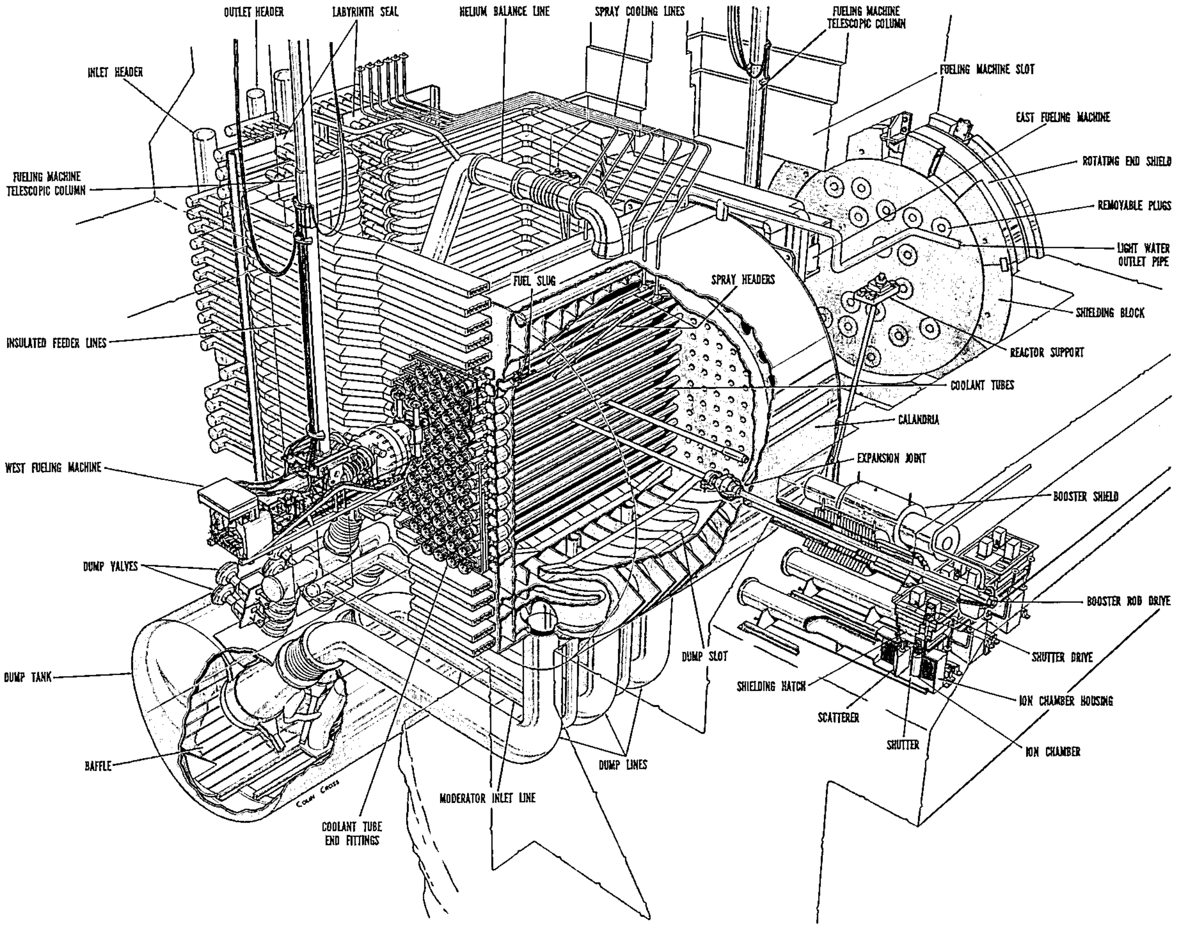
The two end wall units were then set up in a large vertical positioner and the dump port was welded between them.



The barrel shaped inner wall and the spacing ribs between the two walls were next welded into position, and finally the outer wall was welded into place.

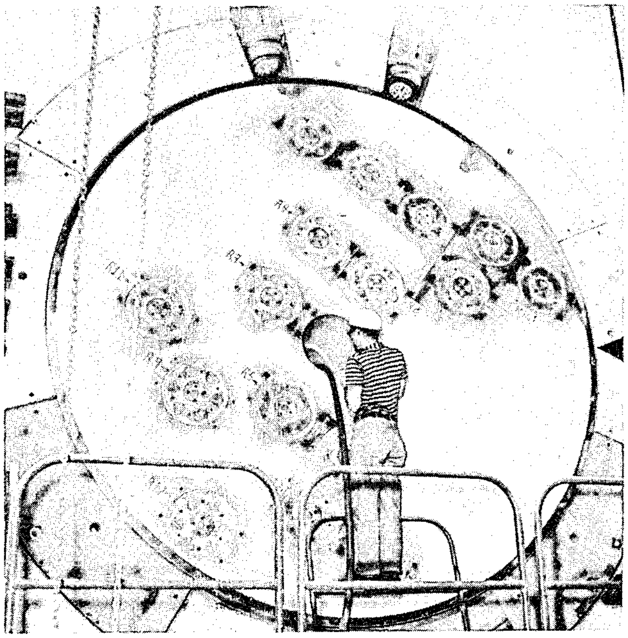


The entire assembly contains more than four miles of aluminum weld and was put through several inspection tests. A final helium leak test indicated essentially zero leakage. The calandria was shipped to the site for installation in June of 1961.

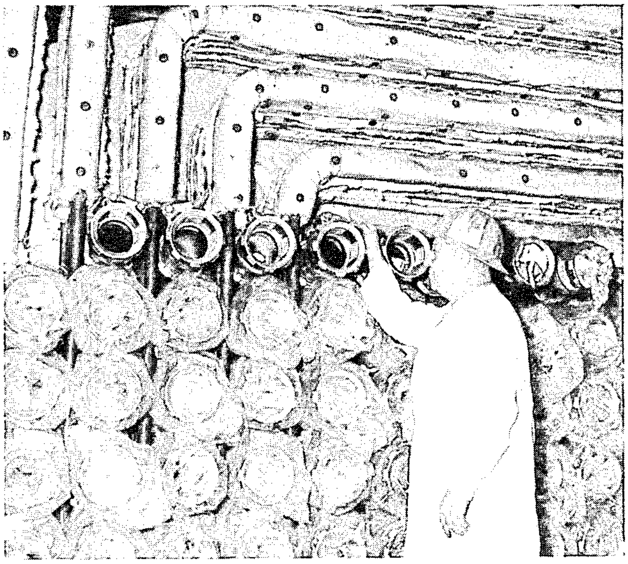


This cut-away illustration shows the calandria in relation to its auxiliary equipment. The installation of the coolant tubes and end fittings was performed in the field.

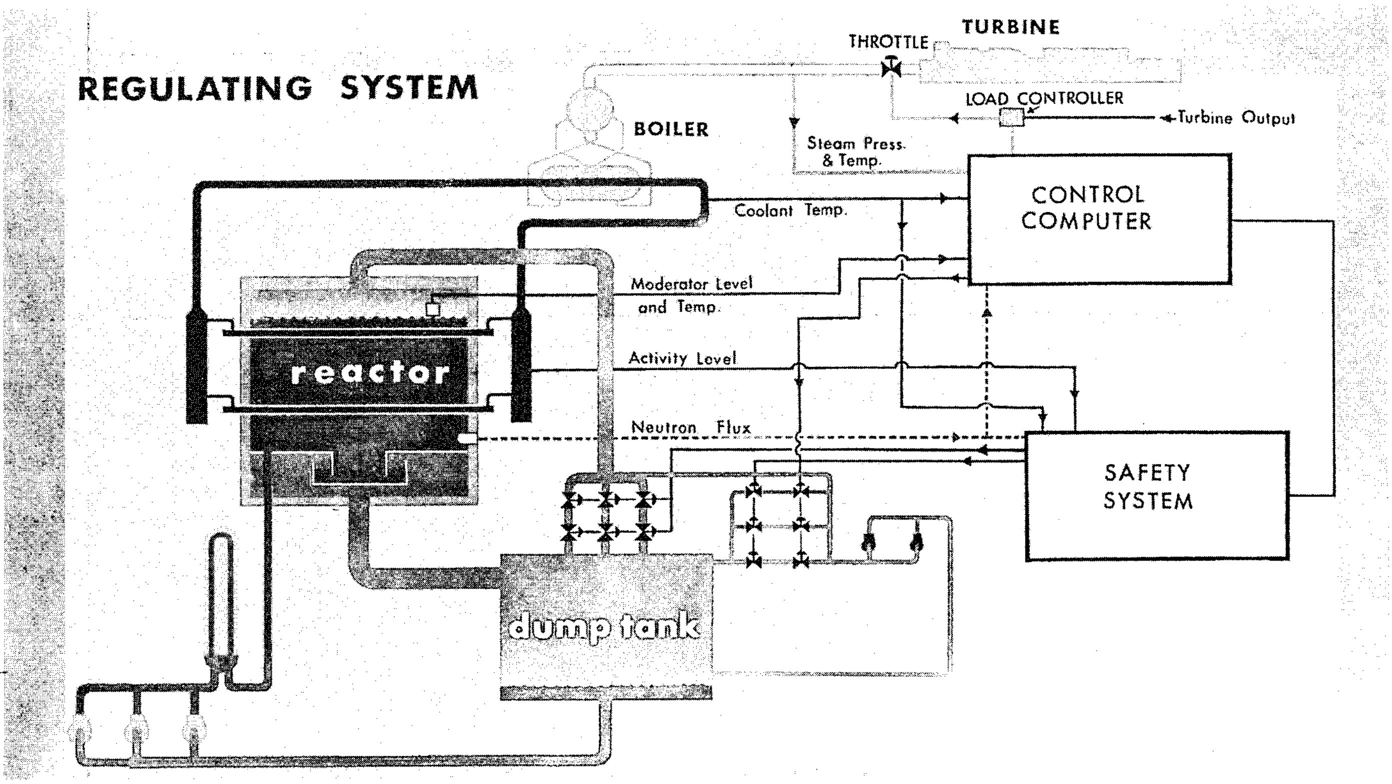
The booster rod will be used only for initial start-up and for poison over-ride during operation of the plant.



Maintenance of the entire reactor core will be carried out by specially designed tooling inserted through holes in the rotating end shields. By rotating the end shields, one of the 17 holes in each shield can be aligned with any specific coolant channel. The rotating end shields are steel fabrications filled with heavy concrete. Each shield is 13 feet in diameter, 4 feet thick and weighs 87 tons.



This picture was taken during installation of the coolant tubes and end fittings. Some of the insulated feeder pipes can also be seen. The end fittings are installed in such a way that they can be disconnected from the feeder pipes and removed without disturbing surrounding end fittings.

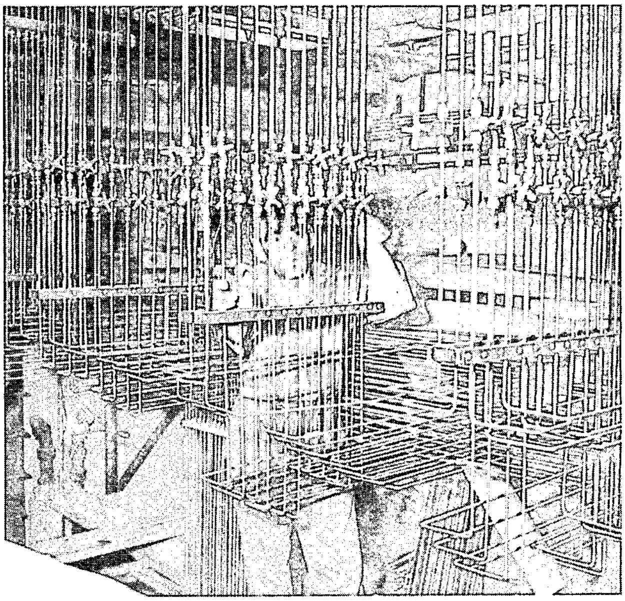


REGULATING SYSTEM

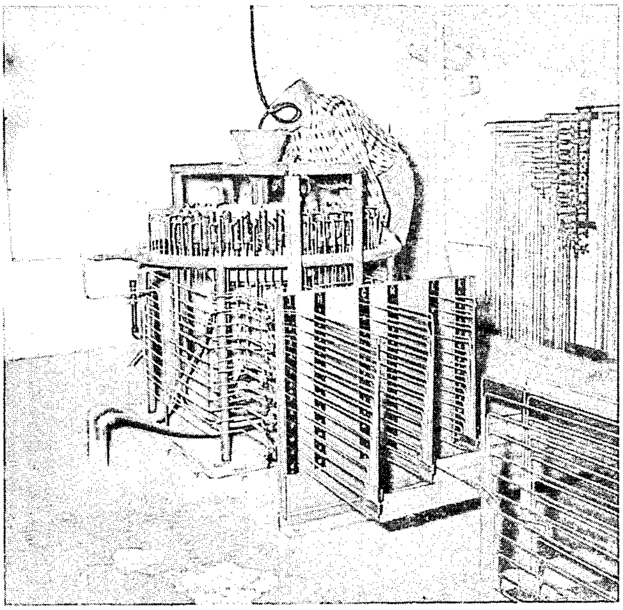
Returning to the overall control system, the regulating system is designed to maintain a constant steam pressure at the turbine throttle. This system responds primarily to deviations in steam main pressure, however other signals originating from such readings as neutron flux or reactor period and coolant temperature exercise limits on the response of the regulating control loop. For example, a break in the steam main would initiate a signal calling for increased power to restore the pressure. However, the neutron flux signal would impose a limit preventing the control system from calling for more than normal power from the reactor. When a significant power change is called for, a signal is relayed to the helium control valves permitting a change in the level of the moderator.

The safety system derives its signals primarily from neutron flux, coolant temperature and pressure monitoring. Whenever the coolant temperature, or the rate of change of coolant temperature, the activity level in the coolant, the neutron flux or the rate of change of neutron flux exceed a specific limit, the safety supervisory system reacts automatically to shutdown the reactor by opening the helium valves and equalizing the pressure to dump the moderator from the calandria. The dump rate is about 100,000 i.g.p.m. which provides a shutdown rate of at least 3 mk in the first second. If the reactor has to be shut down for only a short period of time, a booster rod which contains highly enriched fuel can be inserted into the reactor core to over-ride the effect of the build-up of neutron absorbing fission products in starting up again.

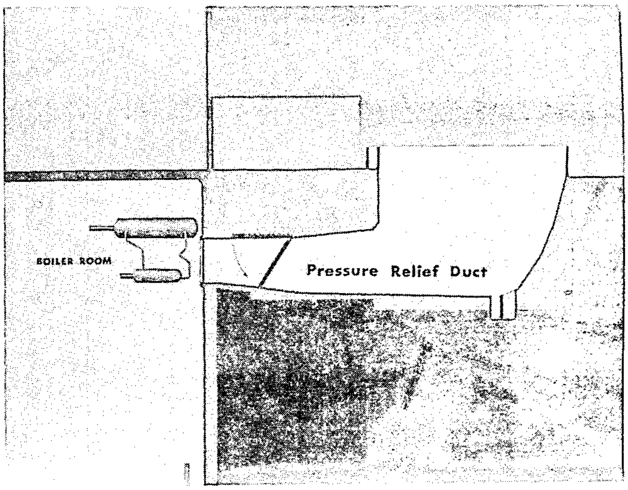
As far as possible, instruments and components are designed for fail safe operation. In addition, both the safety system and the power control loop in the regulating system, as well as all instruments, are triplicated.



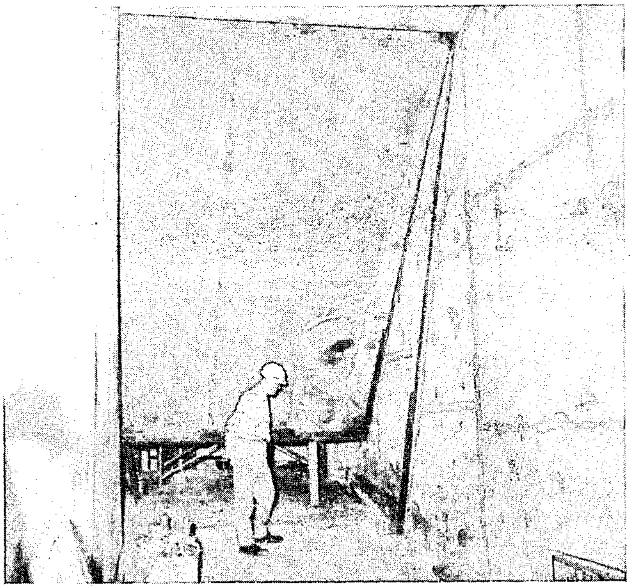
If activity is detected in the coolant system, a sample is extracted from each of the feeders through these monitoring lines and taken to a scanner.



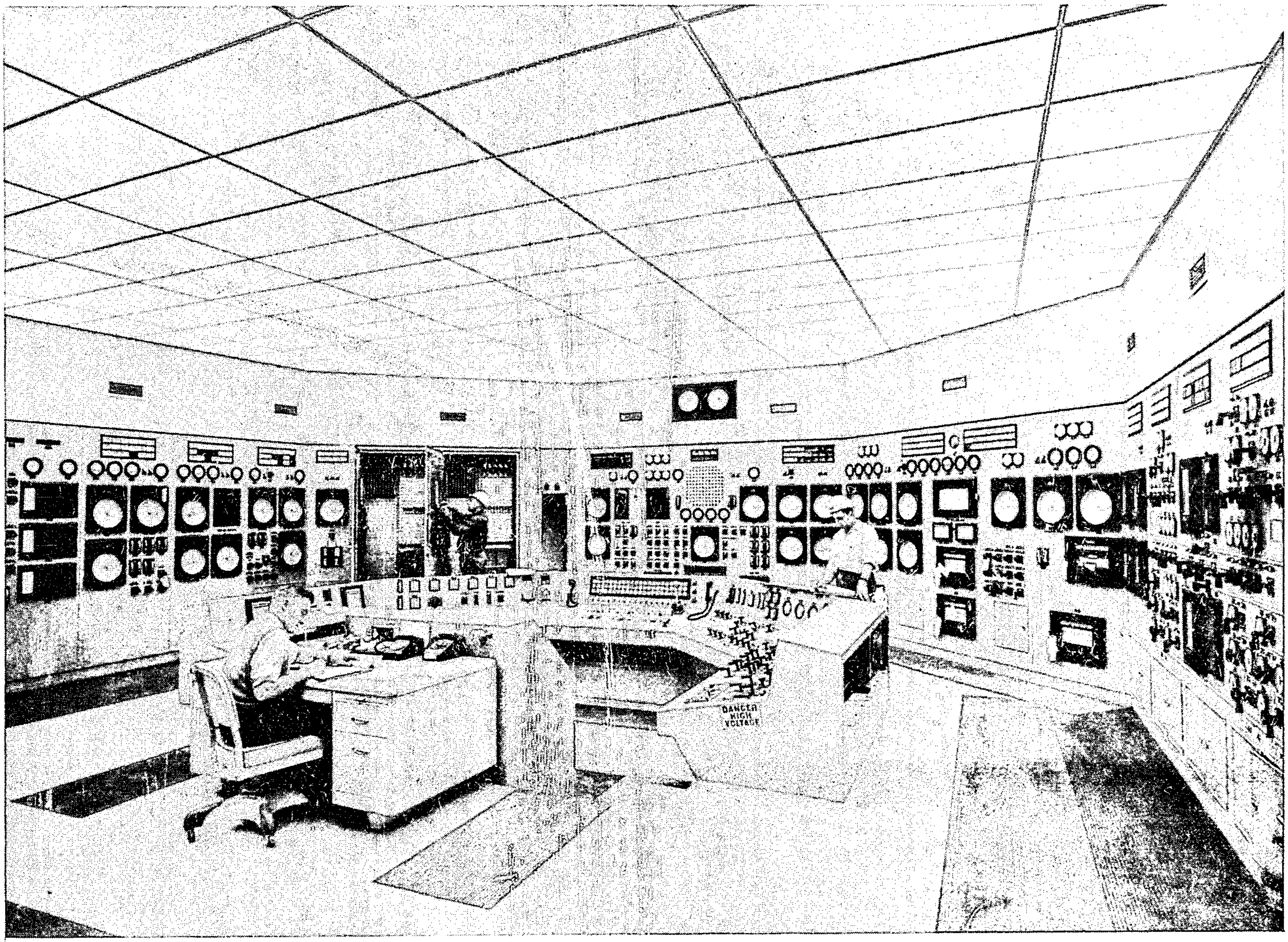
The scanner can then identify the specific coolant tube from which activity appeared.



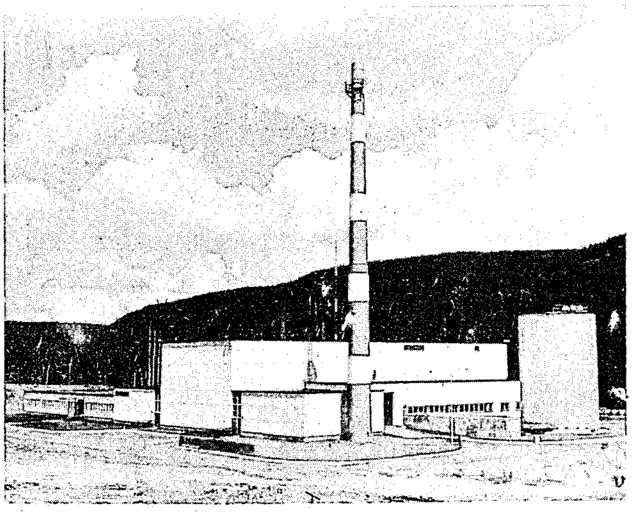
The reactor safety system makes this plant as safe as practicable, and much safer than many conventional plants. However, the very slight possibility of a sudden build-up of pressure in the boiler room has been considered. A pressure relief duct has been constructed adjacent to the boiler room and this duct has a plate glass window which is automatically shattered by an explosive when the pressure inside the boiler room builds up to a certain level. When the initial build-up of pressure has been relieved, approximately within 10 seconds, a steel gate falls into place blocking off the escape of radioactivity.



The photograph shows the gate almost in its closed position.



The main control room, which is located adjacent to the reactor and turbine halls, has all the indicators, recorders and annunciators that supply data upon which all major operating decisions are made. The console contains all controlling switches for routine operation of the plant. The floor mounted panels contain primarily recorders to provide historical data of plant performance as well as switches required to activate certain equipment for plant startup. The lattice arrangement in the background contains dual indicating lights for each lattice position which signal if there is a decrease in flow or an increase in temperature.



This concludes the picture story of the NPD plant and it is hoped that it has proved of interest to you.