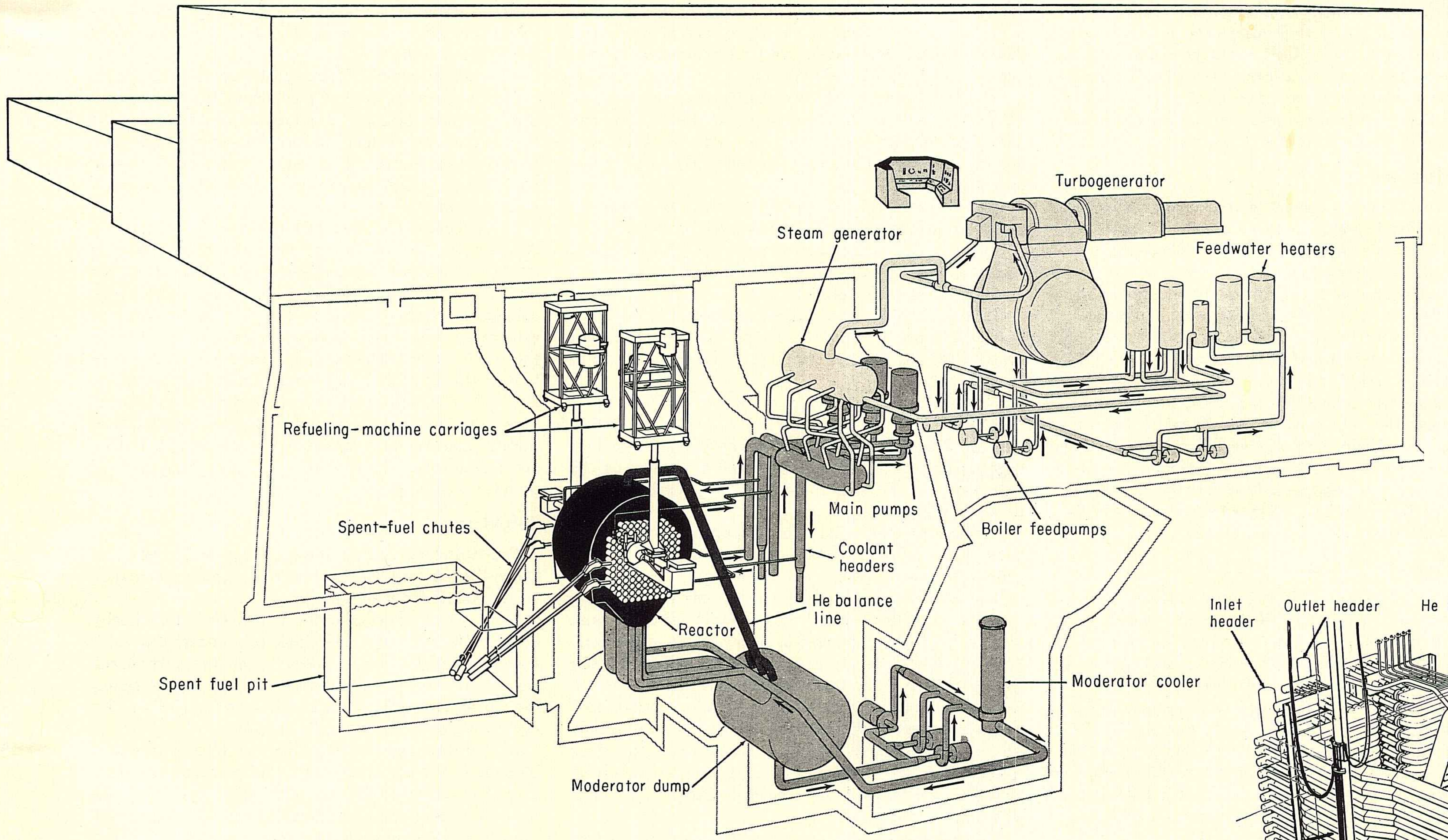
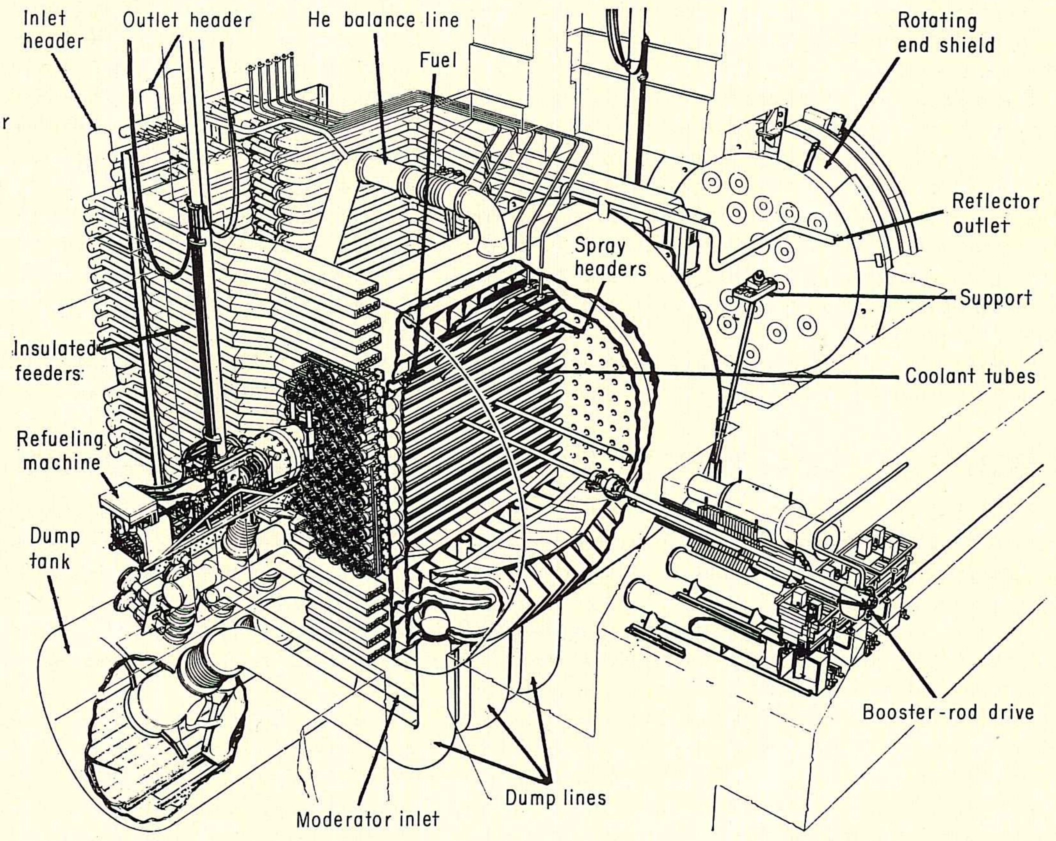
REACTOR FILE . . . No. 13

NPD on the Line

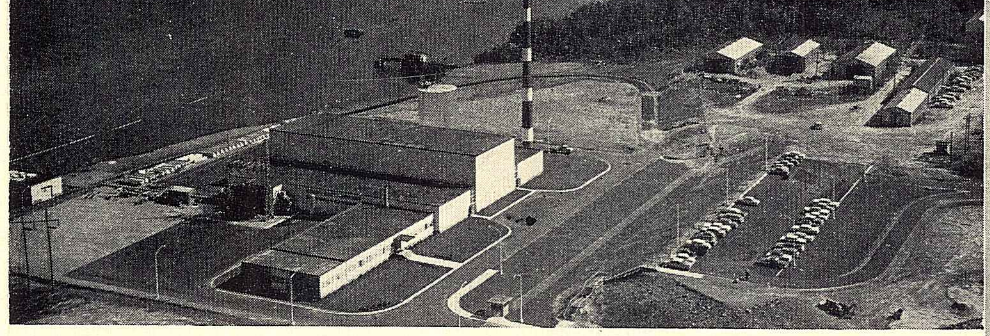




NPD REACTOR VESSEL, which includes H_2O in annular reflector, is enclosed below ground level within $4\frac{1}{2}$-ft heavy (220 lb/ft^3) concrete shield wall that permits access to boiler room for maintenance during shutdown. Another $2\frac{1}{2}$ ft of concrete around boiler room shields personnel from primary-system radiation during reactor operation. NPD containment system is unique in that if primary system ruptures pressure surge would burst diaphragm in pressure-relief duct and let first rush of nonradioactive steam discharge to atmosphere (thus permitting a reactor room that only holds 10 psig and a 5-psig boiler room). Simultaneously same pressure surge would trigger switches and valves that release up to 120,000 gpm dousing water spray over major components (to condense steam and trap fission products) and, after suitable delay, would drop gate to seal relief duct. Fueled booster rod is inserted into core only for startup poison override. Outer reactor vessel is aluminum alloy ~17 ft in dia and 15 ft long; annular space holds H_2O neutron reflector and shield (vessel leak-rate tested to be only 0.3 cm^3/yr at 1 atm pressure difference). Spray system in vessel cools exposed tubes and structure when reactor operates with reduced moderator level. Refueling machines seal onto fuel-channel ends to change fuel while reactor continues to operate. These machines also can be used to change fuel-channel closure plugs or to change the orifice that controls coolant flow in each channel. If a calandria or coolant tube is damaged operators can remove and replace it during reactor shutdown by using special tools they insert through ports in large rotating end shields in reactor room. One operator can perform without difficulty the successive steps of startup. The largely automatic nature of the power-regulation system makes the operator's chief function to perform equipment tests before each step and to inject his decisions into the sequence at various points. The automatic equipment has performed extremely well

Reprinted from NUCLEONICS, November 1962

Printed in U.S.A.



Characteristics of NPD

Location • Rolphton, Ontario, Canada
Owners • Atomic Energy of Canada Ltd. and Hydro-Electric Power Commission of Ontario
Operator • Hydro-Electric Power Commission of Ontario
Designers • Canadian General Electric Co. Ltd. (reactor plant) and Hydro-Electric Power Comm. of Ont. (conventional plant)
Prime contractor • Canadian General Electric Co. Ltd.
Output • 82.5 Mw(th); 20,000 kw(e) gross, 17,500 kw(e) net

Reactor Design Data

Calandria (reactor vessel)

Form, material:	Double-shell horizontal cylinder, Alcan-C54S Al alloy
Nominal dia:	17 ft
Over-all length:	15 ft
Inner wall:	$\frac{1}{4}$ in.
Outer wall:	$\frac{1}{2}$ in. sides, $1\frac{1}{2}$ in. ends
Tubes:	4 in. i.d., 54-mil wall

Reflector

Liquid annulus:	Primary	Secondary
Material:	34,600 lb D_2O	100,000 lb H_2O
Radial thickness—		
—at center:	21.6 in.	>11.8 in. (part shield)
—at ends:	5.6 in.	—

Core

Shape:	Horizontal prism, modified octagonal
No. of channels:	132
Lattice pitch:	10.25 in. square
Channel area:	678 cm^2 total
Eff. core length:	384 cm
—dia:	337.5 cm
Fuel capacity:	16,700 kg

Fuel elements

Type:	UO_2 pellets in Zry-2 tubes	
Enrichment:	0.7% (natural)	
Burnup:	6,300 Mwd/tonne U	
Bundle length:	$19\frac{1}{2}$ in.	
—dia:	~$3\frac{1}{4}$ in.	
Bundles/channel:	9	
Rods/bundle:	7 (in 80 outer channels)	19 (in 52 inner channels)
No. bundles:	720	468
Pellets/rod:	21	24
Pellet length:	0.890 in.	0.782 in.
—dia:	0.943 in.	0.563 in.
—max temp:	≤2,450°F	1,500°F
Cladding:	≥21.4 mil	≥15 mil
—mean temp:	555°F	550°F
Heat flux:	≤146,000 Btu/hr/ft^2	≤148,000 Btu/hr/ft^2
Cross section in channel—		
—UO_2:	32 cm^2	31.1 cm^2
—cladding:	4.78 cm^2	4.49 cm^2
—coolant:	16.60 cm^2	17.84 cm^2

Control system

Coarse control:	1 motor-driven booster rod
—worth:	2.5 mk
—max rate:	~0.01 mk/sec
Fine control:	Moderator volume, varied by gas-balance system
—max rate rise:	0.04 mk/sec at power, 0.29 mk/sec while critical (after cold critical at half tank)
Mod. range:	120–180°F (can drop to 90°F after dumping)
—temp. coef:	−0.013 mk/°F for equil. fuel
Sensitivity:	Holds steam pressure within ±2%
Shutdown:	Moderator dumps
—total worth:	1,000 mk
—in 1 sec:	−3 mk
—in 4 sec:	−20 mk

Nuclear Design Data

Moderator:	1,200 ft^3 D_2O in core
Avg th-neut. ϕ at core center—	
—fuel:	4.2×10^{13} $n/cm^2/sec$
—moderator:	7.9×10^{13} $n/cm^2/sec$
Core avg./max:	0.42

Heat-Transfer Data

Coolant:	22,000 lb D_2O
—flow:	5.14×10^6 lb/hr total; 15.6 ft/sec in central channel
—in:	485°F, 1,040 psig
—out:	530°F, 1,036 psig

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REACTORS
ON
THE
LINE

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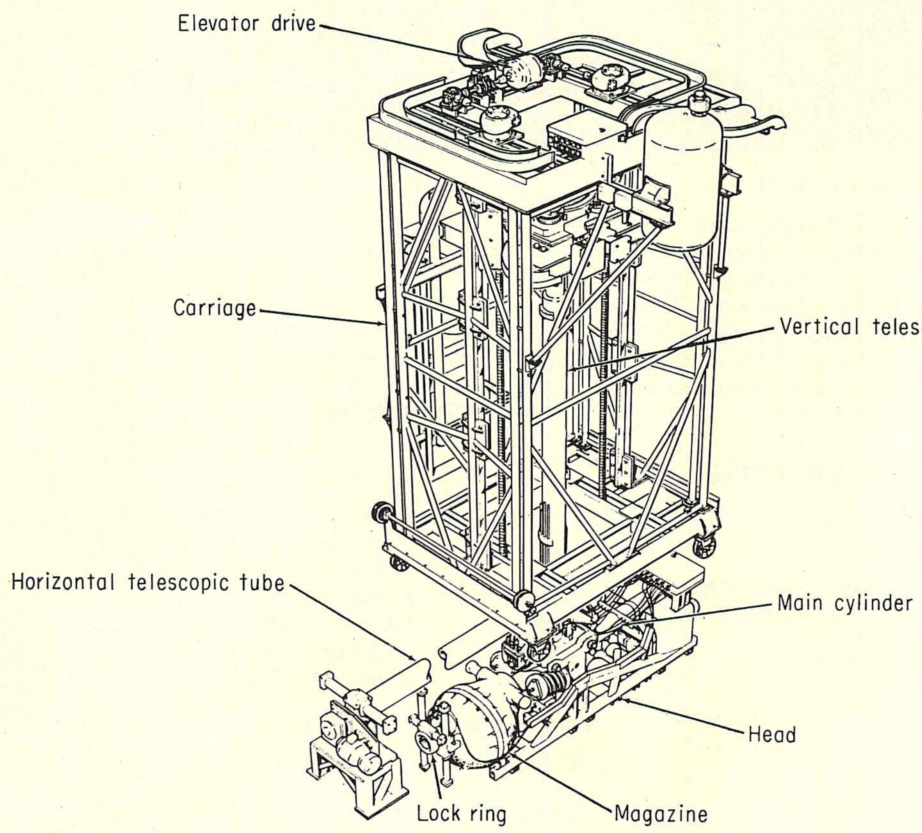
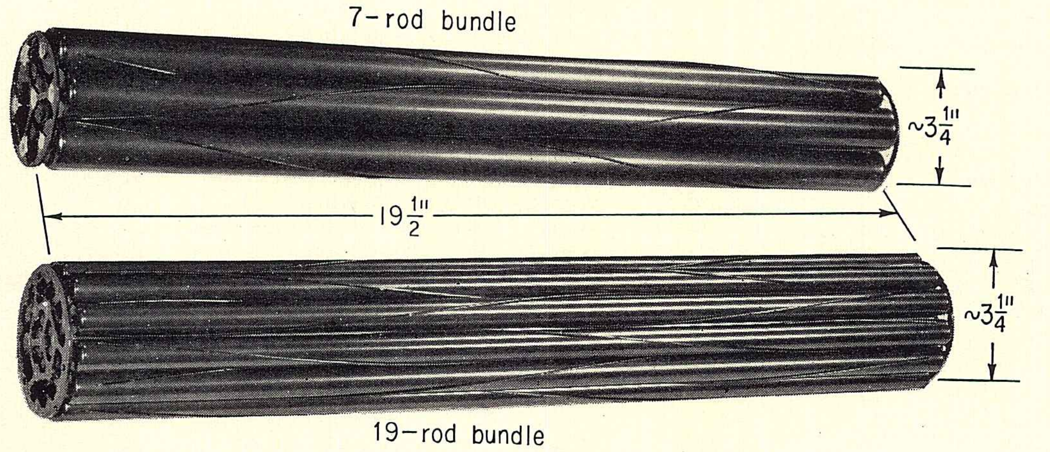
Nuclear
Power
Demonstration



REFUELING-MACHINE HEAD has pneumatically operated lock ring that seals onto fuel-channel end fitting. After the two machines (one loaded with five new fuel bundles, the other empty and ready to take five spent-fuel bundles) are clamped onto opposite ends of a fuel channel, heads are filled with D_2O and pressurized to match reactor pressure, machines remove end-closure plugs from channel and store them in magazines within heads. Then ram in loaded machine pushes new bundle into fuel channel, thus moving all bundles in channel and pushing a spent bundle into opposite machine, which moves it into storage magazine in head. After replacing closures, depressuring and draining, the machines can move to another channel to repeat the process. Internal mechanisms (such as ram, magazine) in the head operate hydraulically using heavy water as the working fluid



FUEL BUNDLES, which are of two types, all contain natural-UO_2 pellets in Zircaloy-2 tubes that are spaced by Zircaloy wires wrapped and spotwelded around tubes in double-course helix. Wires also cause coolant mixing; nine fuel bundles are loaded into each reactor channel. The 468 bundles in 52 inner channels each have 19 fuel rods of only ½ in. dia (to help transfer the greater heat generated near the core center); but 720 bundles in outer 80 channels have 7 fuel rods of 1 in. dia

Description of NPD

NPD is a pressurized-heavy-water-cooled and -moderated natural-uranium fueled, horizontal-pressure-tube reactor. It is (a) fueled on a once-through basis, (b) refueled while operating, (c) controlled by varying moderator volume and temperature and (d) it has a combined pressure-relief duct and dousing system to simplify containment problems.

NPD was built to prove the technical feasibility and reliability of the Canadian heavy-water power-reactor concept. Emphasis is placed on neutron economy, high burnup and the resulting inherent simplicity of the once-through mode of fueling. Because the Canadian fuel-cycle concept considers spent fuel as being worthless in fuel-cost calculations (after discharge from the reactor spent fuel is stored safely and cheaply on the station site) it is economically independent of reprocessing problems and associated cost uncertainties.

Reactor Vessel

Made of aluminum alloy, the reactor vessel (or calandria) is a horizontal, barrel-shaped shell $\sim$12.6 ft long and 14.7 ft in diameter at the center; it tapers to 12 ft dia at the ends. This inner vessel contains the heavy-water moderator and fuel channels. It is surrounded by another cylindrical tank of the same material (but $\sim$15 ft long and 17 ft in diameter) to form an annulus and double-end walls that hold H_2O as a neutron reflector and shield. For the horizontal fuel channels, 132 thin aluminum tubes pass through the vessel between the end sheets. These 132 channels, which are spaced on $10\frac{1}{2}$-in. centers in a square lattice, are arranged in a 12 × 12 array with three sites omitted from each corner to form a modified octagon. The complete vessel weighs $\sim$16 tons empty and is suspended by four steel rods to allow thermal expansion.

Dump port. A port at the bottom of the structure is shaped to provide a gas-liquid interface whereby the difference in helium pressure between this face and the upper region of the calandria supports the moderator at the desired level in the calandria. For emergency shutdown the controls equalize gas pressures so the moderator spills rapidly over the dump port and then flows through three 24-in. pipes into an aluminum dump tank below the calandria.

Fuel channels. Each of the 132 channels consists of an aluminum calandria tube (4-in. i.d. and 0.052-in. wall) within which is a Zircaloy-2 coolant tube ($3\frac{1}{4}$-in. i.d. and 0.163-in. wall). For thermal insulation air at atmospheric pressure circulates slowly through the annulus. The ends of the Zircaloy tubes are rolled into stainless-steel end fittings attached to the vessel end sheets. The end fittings provide radial joints for the feeder-pipe connections to the external primary-coolant system; they also contain seal closure plugs, which the fueling machines remove for refueling operations. An orifice attached to the closure plug at one end of each coolant tube adjusts coolant flow pattern in the core; coolant flows in opposite directions in adjacent channels.

Fuel Elements

The fuel elements consist of rod bundles of natural-uranium-dioxide pellets in sealed Zircaloy-2 tubes. The initial charge consists of 1,188 fuel bundles, nine in each horizontal fuel channel.

To make the fuel elements UO_2 powder was pressed into pellets and the pellets were sintered and ground to precise diameter before being loaded into the Zircaloy tubes whose one end had been capped and sealed by a tungsten-arc weld. After air was pumped from the tubes argon was added and a Zircaloy cap was welded on to seal the tube. After two Zircaloy wires were wrapped in a helix and spotwelded around each rod (except for the six rods for the inner part of the 19-rod bundles) the rods were assembled between Zircaloy end plates to form bundles. Each 19-rod bundle weighs 36 lb, 33 of which are uranium dioxide.

Heat-Transfer System

Heavy-water coolant (12,000 gpm) enters the reactor fuel channels at 485°F and 1,040 psig and leaves heated to 530°F and 1,036 psig. In the steam generator the hot D_2O turns 296,000 lb/hr of 300°F H_2O feedwater into dry saturated steam at 448°F and 400 psig.

Steam generator. The single steam generator has a horizontal U-tube-and-shell heat exchanger (2,099 Inconel tubes of ½ in. dia provide 6,200 ft^2 of surface) connected to an overhead steam drum (60 in. dia and 25 ft long) by risers and downcomers. The D_2O pressure drops 21.1 psi as it passes through the steam generator at up to 15.4 ft/sec.

Piping. Main primary-coolant piping is of Schedule-80 ASTM-A106 carbon steel of 16 in. dia; in the pump branches pipe dia is 10 in. The 264 feeder pipes ($1\frac{1}{2}$ in. dia) that connect the fuel channels to appropriate headers are flexible enough to allow thermal expansion of the reactor-coolant tubes and related components. Although there are no isolation valves in the feeders the D_2O in the pipes can be frozen to permit maintenance work.

Main pumps. Each of the three (one of which is a spare) 800-hp single-stage vertical centrifugal pumps moves 6,000 gpm with a 140-psi head. A leakoff system collects D_2O between the two shaft seals on each pump. Pump material is steel containing 11–13% chromium. Flywheels maintain circulation for $\sim$3 min after a power failure; natural convection cools the reactor after pump rundown.

Standby cooling. When it is necessary to service the main cooling system during reactor shutdown NPD operators switch on an auxiliary circuit. It has two 1.5-hp pumps that push 120 gpm of D_2O through a 1-Mw shell-and-tube heat exchanger.

Reflector cooling. During reactor operation two 10-hp pumps (a third is a spare) circulate 1,200 gpm of light water from the reflector through a shell-and-tube heat exchanger.

Control System

The NPD system is unique in the field of power-reactor design in that reactivity is controlled by regulating the heavy-water moderator volume (by level) or density (by temperature) or both.

Moderator level. The moderator is pumped continuously from the dump tank to the calandria and returns through the dump port to the dump tank. The pressure difference between the helium cover gas in the upper region of the calandria and the helium in the dump tank determines the net amount of heavy water in the core. This pressure difference is controlled by helium transfer (at up to 180 ft^3/min) between the two regions. The two 10-hp helium blowers are shunted by control valves in a fail-safe system. (Equalization of gas pressure allows the moderator to fall through the dump port and three 24-in. pipes into the dump tank, thus rapidly shutting down the reactor in an emergency.) There are 1,500 ft^3 of helium in the system.

Moderator density. Heat is generated in the moderator by radiation absorption and heat transfer from the primary coolant system. Temperature (and thus density) is controlled between 120 and 180°F by circulating the moderator continuously through a 6.5-Mw shell-and-tube heat exchanger. Two 50-hp pumps (a third is a spare) move the D_2O at up to 1,560 gal/min.

Booster rod. After shutdown a booster rod containing enriched uranium is driven into the core; it introduces enough reactivity to stretch the 12-min poison-override time to $\sim$35 min.

Regulating system. The regulating system maintains constant steam pressure at the turbine throttle by controlling reactor output. The system responds primarily to change in main steam pressure, but signals originating from reactor neutron flux, reactor period and coolant temperature impose limits on the demands of the main regulating loop.

Safety controls. The safety system monitors neutron flux, reactor period, coolant temperature and rate of change of coolant temperature. Deviations from set limits of any of these variables cause reactor shutdown by equalizing helium pressures to dump moderator from the calandria. All control channels capable of shutting down the reactor are completely triplicated and arranged so that a trip signal from any single channel will sound an alarm; but signals from two channels are required to cause shutdown. This not only helps prevent shutdown through spurious fault signals but it also permits testing and maintenance of any channel without disturbance or sacrifice of protection.

Refueling

The two identical refueling machines are stored in an above-the-reactor (and shielded from it) room where they are accessible for maintenance.

Sequence controls take the machines automatically through the refueling cycle; interlocks ensure that each step is completed satisfactorily before the next starts. Electric motors drive the carriage and telescopic columns for coarse horizontal, vertical and homing motions, but fine motion is by oil hydraulic motors.

In operation new fuel is loaded one bundle at a time into one end of a channel while a fully irradiated bundle is discharged from the other end. Fuel is loaded from opposite ends of adjacent channels to maintain an axially symmetrical flux pattern for optimum reactivity. Each coolant-tube assembly connects to inlet headers so that coolant flow opposes fuel movement.

Startup and Early Operating Experience

NPD first went critical April 11, 1962, generated steam May 8, turned the turbine May 12, delivered electricity to Ontario Hydro on June 4 and generated the full 20 Mw(e) gross on June 28.

In the shakedown period from June 4 to August 8 NPD generated 262 Mwd electricity during 533 service hr.

Scrams. During the initial power run-up period between June 4 and 28 operation was interrupted 35 times, 13 of which were deliberate. Of the 22 unplanned scrams, 10 were caused by a faulty bearing in a charging pump (signalled by low water level in a surge tank), six were caused by overly rapid load changes and the other six occurred through spurious signals in one control channel while a second was undergoing maintenance.

Prestartup preparations, tests. On-site operator training and early system shakedown began in September 1960. Construction drew to a close a year later and prestartup testing was in full swing by December, 1961. Because reactor-system piping is carbon steel, constructors and operators made special efforts to make and keep the system tight, dry and clean before loading coolant or fuel.

Fueling. Fuel loading, which commenced March 1, ended March 21 as the first charge of 1,188 fuel bundles (weighing nearly 20 tons) was completed. The 20 days' work included a 2-day interruption for minor repairs on the two fueling machines.

Heavy-water losses. To date D_2O loss has been about half that expected; further, $\sim$90% of the losses were from a dozen specific minor events of a nonrepetitive nature. By means of early warnings the leak-detection system has been very effective in reducing leakage.

Routine startups. When the station is off the line operators prefer to keep the reactor critical and at 0.1% power to keep the main cooling system at the normal control pressure of 1,034 psig. If it is at only 100°F (which permits maintenance of boiler-room equipment) operators bring the reactor to 6% power for the 2 hr it takes to bring the system to 500°F at the 200°F/hr limit imposed by thermal stresses in major components. Steam is generated in the boiler during warmup so piping can be warmed and turbine rolled on steam before ideal steam quality is obtained for power operation. Thus from a cold (100°F system temperature) start the turbine can be loaded in $\sim 2\frac{1}{2}$ hr.

If the primary system is held at 300°F during standby thermal stresses do not impose the same limits on heat-up and runup rates. Thus from complete shutdown the reactor can be brought to 60% power within 20 min and steam can be raised to 448°F and 400 psi within another 40 min. Provided the turbine has been kept warm, the generator then can be synchronized and the set loaded at its normal rate. Starts of this type have been made in a total time of 100 min.

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