CA9110910

INIS-mf--12932

Ontario Hydro's Nuclear Program Design and Construction Status

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CNA Conference
Saskatoon, Sask.
Canada
June 3-6, 1984

The address today will briefly describe Ontario Hydro's nuclear program, take a look at the design and construction status and touch on the future from Ontario Hydro's perspective.

As can be seen from Figure 1 Ontario Hydro still relies heavily on nuclear power.

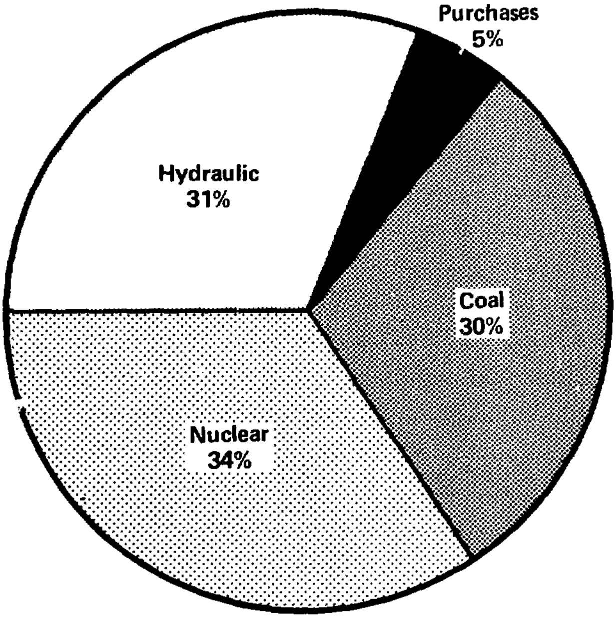


FIGURE 1
ONTARIO HYDRO
SOURCES OF ENERGY
1983
(117,971 Million kW·h)

Approximately 34 per cent of our 1983 energy production of 117,971 million KW.h was nuclear-fuelled, the other two-thirds being made up from approximately 30 per cent coal-fuelled and 31 per cent hydraulic with the remainder from purchases.

The nuclear portion was produced by 12 operating units located at : NPD, Douglas Point, Pickering 'A', Bruce 'A' and Pickering 'B'. The basic station data is shown on Table 1.

TABLE 1
NUCLEAR FUELLED GENERATING STATIONS IN OPERATION

		Generating Capacity (MW Net)		
Station	No. of Units	Unit	Station	In-Service
NPD	1	20	20	1962
Douglas Point	1	200	200	1967
Pickering A	4	516	2064	1971-73
Bruce A	4	741	2964	1977-79
Pickering B	2	516	1032	1983-84
	12		6280	

There are also ten nuclear units in the design and construction phase, located at Pickering 'B', Bruce 'B' and Darlington sites. The basic data on these stations is shown on Table 2.

TABLE 2
NUCLEAR FUELLED GENERATING STATIONS UNDER CONSTRUCTION

		Generating Capacity (MW Net)		
Station	No. of Units	Unit	Station	Projected In-Service
Pickering B	2	516	1032	1984-85
Bruce B	4	781	3124	1985-87
Darlington	4	881	3524	1988-92
	10		7680	

In summary, Ontario Hydro has 6,280 MW of nuclear generation operating, and 7,680 MW under construction. By 1992 our nuclear generating capacity will be 13,960 MW.

Operating 1984	**6 280 MW**
Under Construction	**7 680 MW**
Total Operating 1992	**13 960 MW**

By 1992 nuclear generation will be providing approximately 65 per cent of our total energy needs, with hydraulic supplying 24 per cent, coal nine per cent and two per cent from purchasing, as shown on Figure 2.

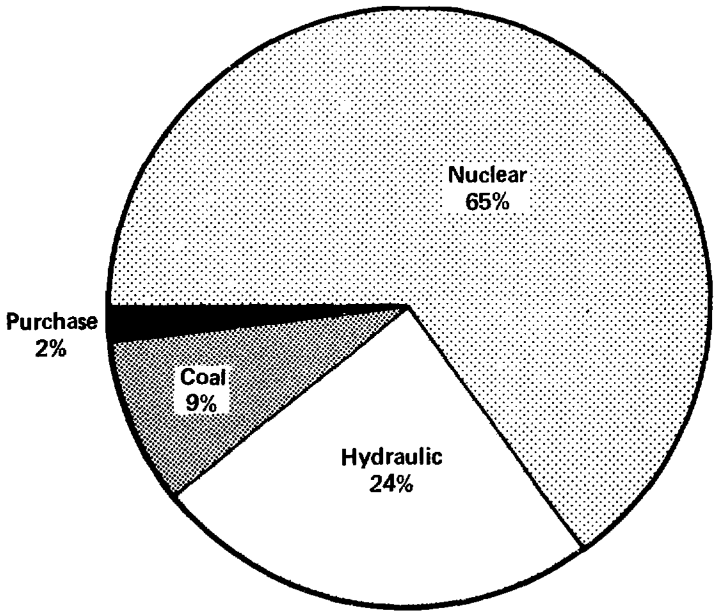


FIGURE 2
ONTARIO HYDRO
SOURCES OF ENERGY
1992
(144 218 Million kW•h)

Figure 3 shows the general location of the stations in Southern Ontario.

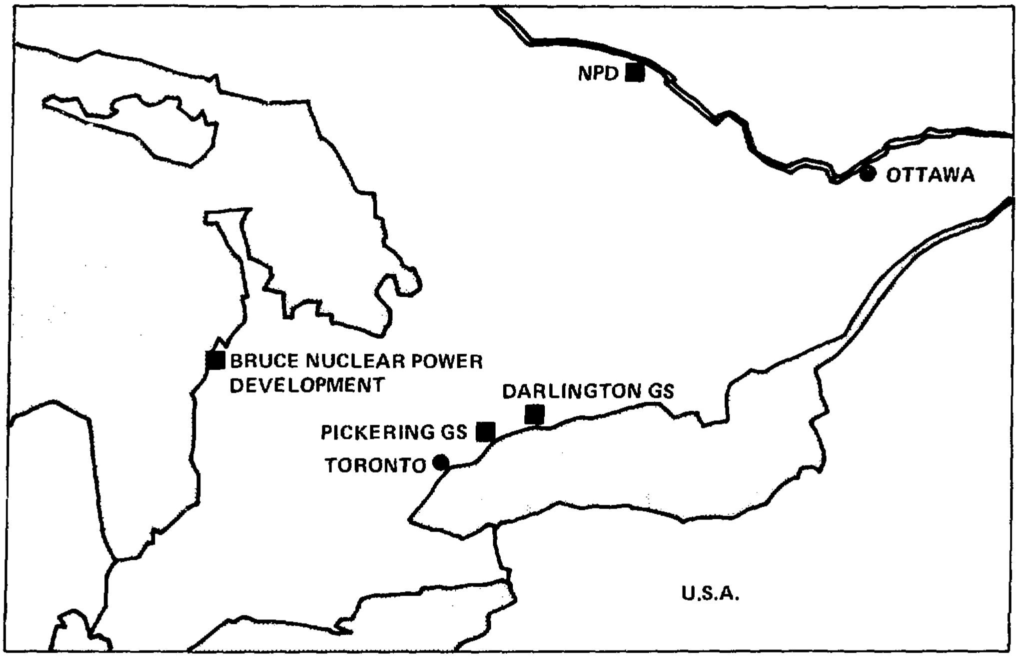


FIGURE 3

ONTARIO HYDRO
NUCLEAR GENERATING STATIONS

DESIGN AND CONSTRUCTION STATUS

Before reviewing the status of each station under construction, here is a brief description of the status of the Pickering 'A' Large Scale Fuel Channel Replacement Program (LSFCRP).

Subsequent to the cracking of a pressure tube at Pickering 'A' Unit 2, in August 1983, Hydro decided early in March 1984 to accelerate the design work aimed at replacement of Units 1 and 2 pressure tubes. The decision to proceed immediately with this work enables Hydro to make the best possible use of both financial and human resources. Retubing of the two units will be completed by 1987. The Zircoloy-2 pressure tubes will be replaced by zirconium-niobium tubes, the type used in all CANDU reactors built after Pickering Units 1 and 2.

In addition, the garter spring repositioning program for Pickering 'B' and Bruce'B' units is under way.

Pickering 'B' - Construction Status

Pickering 'B' is a 2064 MW nuclear generating station located on the shores of Lake Ontario about 32 km east of Toronto. Scheduled for completion in 1985, the station will consist of four units each capable of producing 516 MW.

The first two units of the 'B' station were declared in-service in May 1983 and February 1984.

Figure 4 gives an aerial view of the Pickering Generating Station with the 'B' station in the foreground.

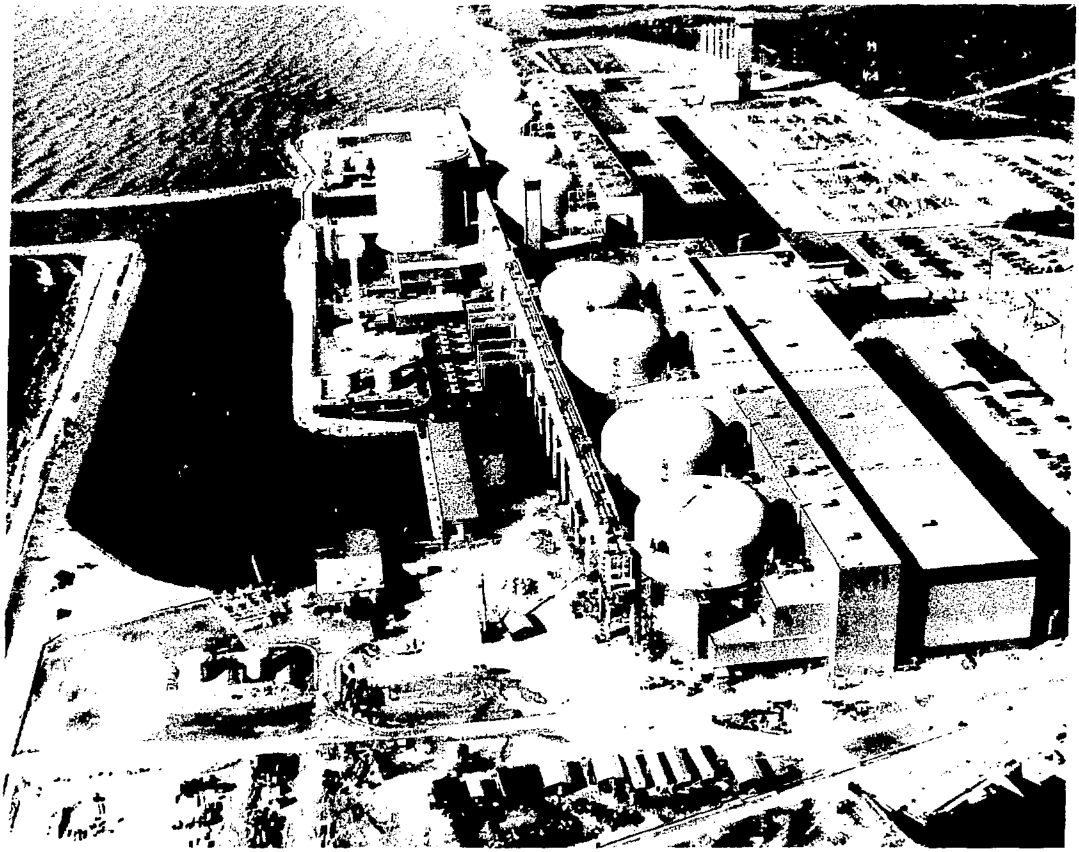


FIGURE 4
PICKERING GENERATING STATION

Cost, manpower and in-service date information for Pickering 'B' is shown on Figure 5.

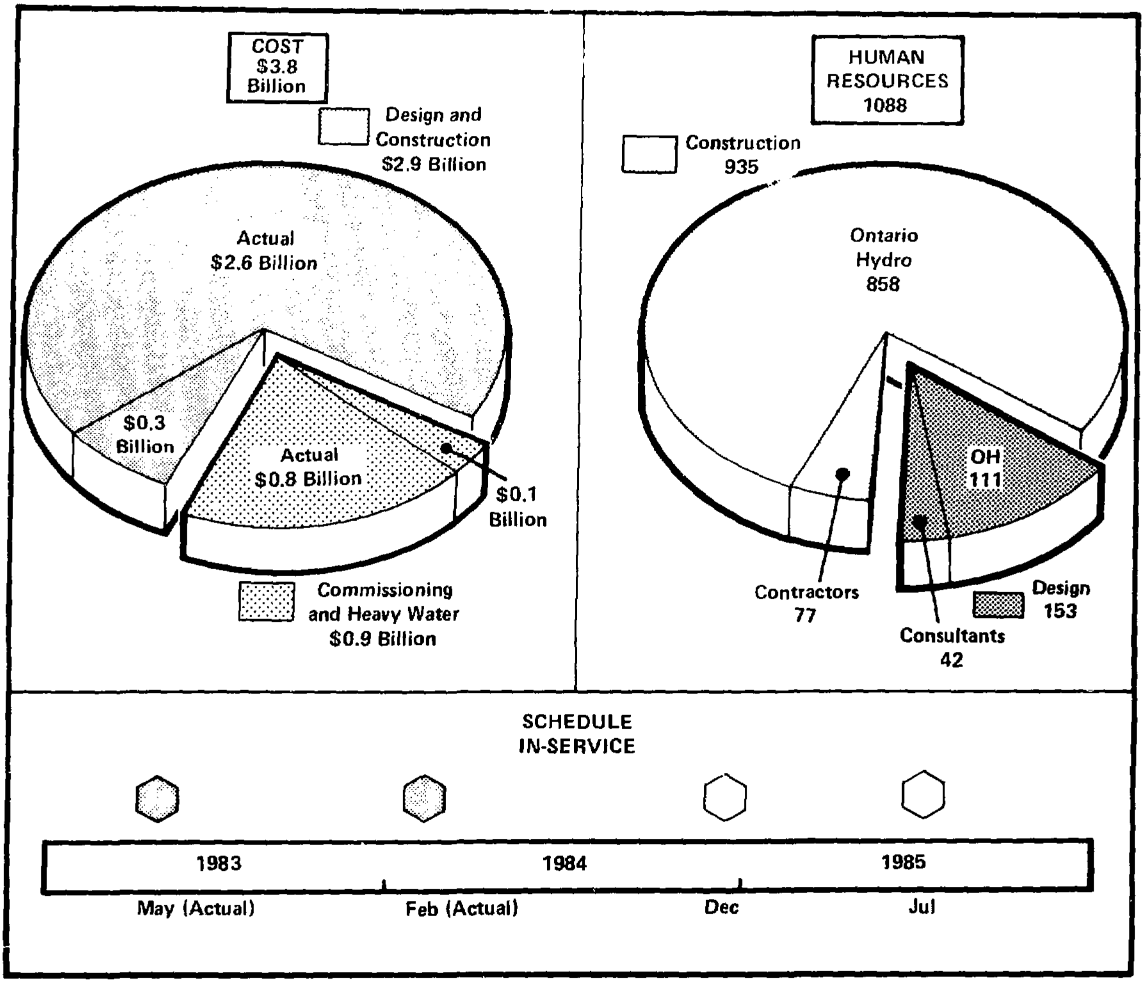


FIGURE 5

PICKERING GENERATING STATION B
STATUS – MARCH 1984

Type:	CANDU
No. of Units:	4
Unit Size:	516 MW net
Station Size:	2064 MW net

- The cost-pie depicts the make-up of the total project cost and the expenditure status as of March 1984.
- The manpower-pie depicts the make-up of the total project personnel as of March 1984.
- The schedule shows the planned in-service dates of each unit.

It will be recalled that problems were experienced with the steam generators on Pickering 'B'. During the manufacturing process, heat treatment of the major welds caused damage to the tubes. This necessitated a rebuild program and the steam generators installed on units 5 and 6 had to be returned to Babcock and Wilcox. This resulted in an in-service date delay of an average of 23 months. Units 5 and 6 are now in operation.

With respect to units 7 and 8, the construction activity is continuing at a high level with major systems already turned over for commissioning, or being tested. Criticality for these units is expected for August 1984 and April 1985 respectively, with in-service dates scheduled for December 1984 and July 1985 respectively.

The installation of the high pressure emergency core injection system was a late change to the project brought about to enhance reliability and safety. Units 5 and 6 have already been equipped with the system and the construction is progressing for the other two units.

It was also decided to upgrade the emergency coolant injection system in Pickering 'A' to a high pressure system. The installation will be completed during unit outages for the Pickering 'A' units. The final installation into all units is scheduled to be completed by 1989.

Bruce Generating Station B - Construction Status

Bruce B is a 3124 MW nuclear generating station located in the Bruce Township, approximately 3 km south of the 'A' station. Scheduled for completion in 1987, the station will consist of four units, each capable of producing 781 MW.

A general aerial view of the 'B' station is shown at Figure 6 including Douglas Point, the Heavy Water Plants and the 'A' station in the background.

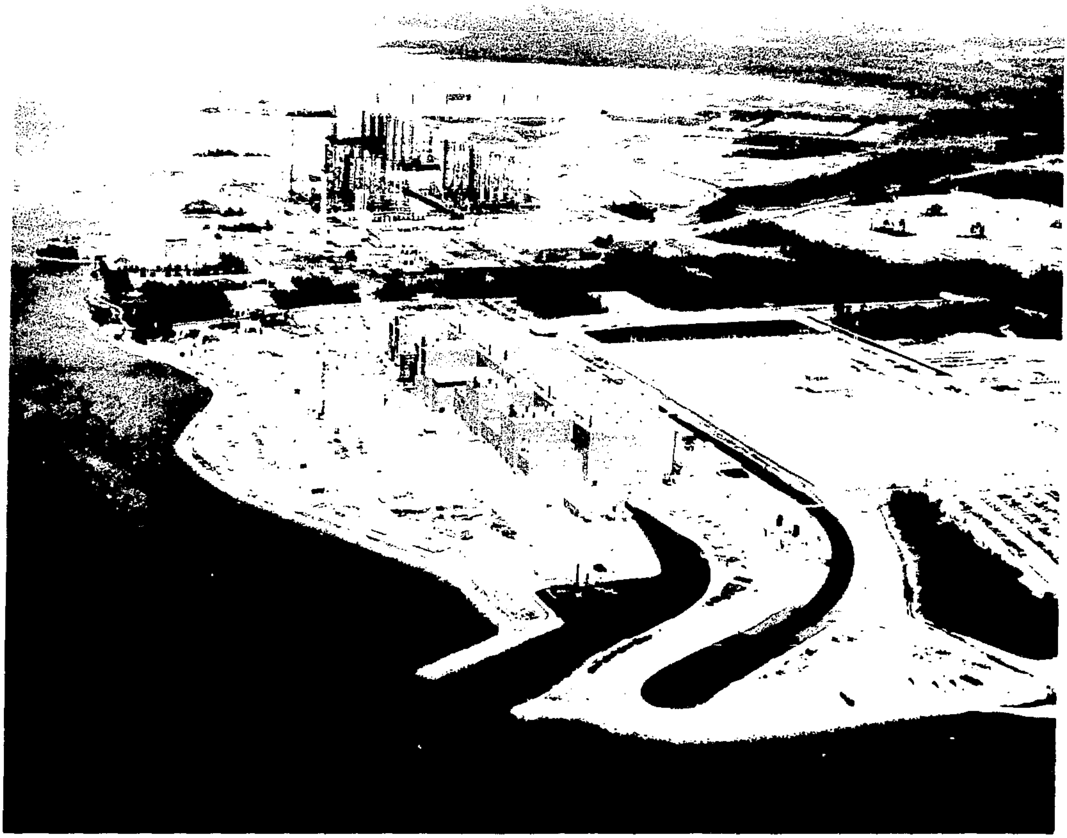


FIGURE 6
BRUCE GENERATING STATION B

Cost, manpower and in-service date information is shown on Figure 7.

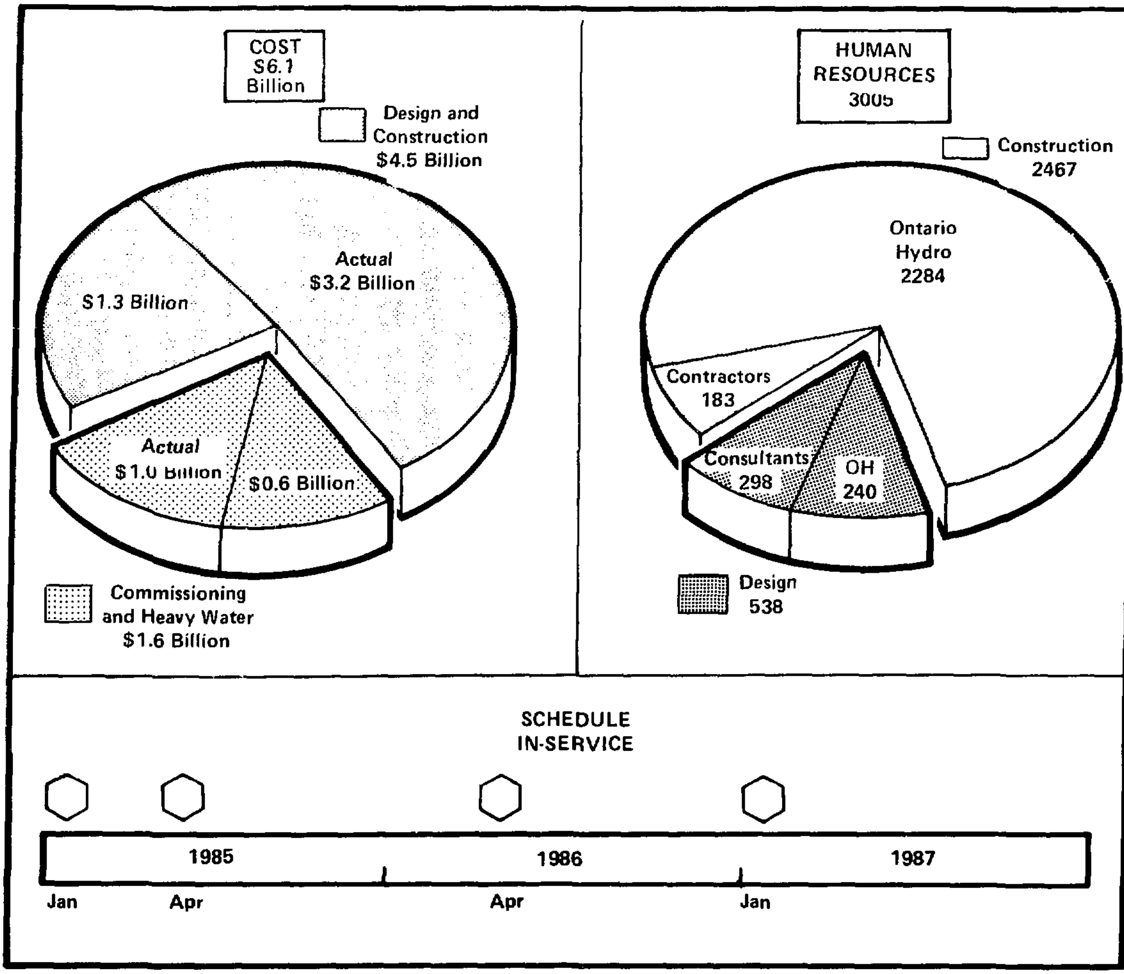


FIGURE 7
BRUCE GENERATING STATION B
STATUS – MARCH 1984

Type:	**CANDU**
No. of Units:	**4**
Unit Size:	**781 MW net**
Station Size:	**3124 MW net**

- The cost-pie depicts the make-up of the total project cost and the expenditure status as of March 1984.

- The manpower-pie depicts the make-up of the total project personnel as of March 1984.

- The schedule shows the planned in-service dates of each unit.

Bruce Generating Station 'B' - Construction Status

The civil works program for the station is now essentially complete.

On unit 6, all associated systems that allow the reactor to go critical were commissioned in 1983. The scheduled reactor critical date of September 1983 was missed due to mandatory implementation of design changes in the negative pressure and shutdown systems. There was a further delay when an investigation, as a result of the Pickering 'A' incident, showed displacement of the garter springs supporting the fuel channels. A program is in hand to reposition garter springs within acceptable limits, and the new projected date for reactor critical is June 1984, with the in-service date scheduled for January 1985.

On unit 5, more than 80 per cent of the systems have been turned over for commissioning. Main commissioning activities are concentrated on moderator, primary heat transport, feedwater and shutdown systems. This unit will also require repositioning of garter springs which will result in a delay to unit start up. The first critical date for this unit is now predicted to be October 1984, with the in-service date scheduled for April 1985.

Steam generators have been installed on unit 7 and the moderator system installation is now complete. Turbine generator installation is about 70 per cent complete. Garter springs must also be repositioned in this unit, but no schedule delays are anticipated with the in-service date scheduled for April 1986.

On unit 8, the calandria is in position. The western bank of steam generators and preheaters has been installed, and reactivity deck installation is under way. Fuel channels on this unit are being installed incorporating a new design of garter spring. The in-service date for this unit is scheduled for January 1987.

Another item of significance relating to Bruce 'B' is the uprating of four turbine generators utilizing additional steam available from the reactor. This additional steam will raise the net output of each unit from 756 to 781 MW.

At Bruce 'A', the fuel handling system extension has been completed. The installation of the high pressure emergency coolant injection system is nearing completion; it is planned to tie the system into units 3 and 4 this year during maintenance outages.

Darlington GS - Status

Darlington is a 3524 MW nuclear generating station located on the shores of Lake Ontario about 65 km east of Toronto. Scheduled for completion in 1992, the station will consist of four units each capable of producing 881 MW.

The Ontario government announced approval of the construction of the four unit, 3500 MW Darlington Nuclear Generation Station on April 18, 1977, and the project was subsequently released on June 8, 1978. Between the release and the present time, the in-service dates for the four units were changed four times. The in-service dates were deferred in 1979, 1980, advanced in 1981, and Units 3 and 4 only were deferred in 1982. In total, the in-service dates have been deferred 1-1/2 to 4-1/2 years since the project was approved for a first unit in-service date of 1985. The current in-service dates for the four units are May 88, February 89, November 91 and August 92.

The total cost of Darlington, which includes commissioning, heavy water and training is $10.9 billion. In terms of constant (end of 1983) dollars, the total cost is $5.4 billion.

Figure 8 gives a general view of the construction site.

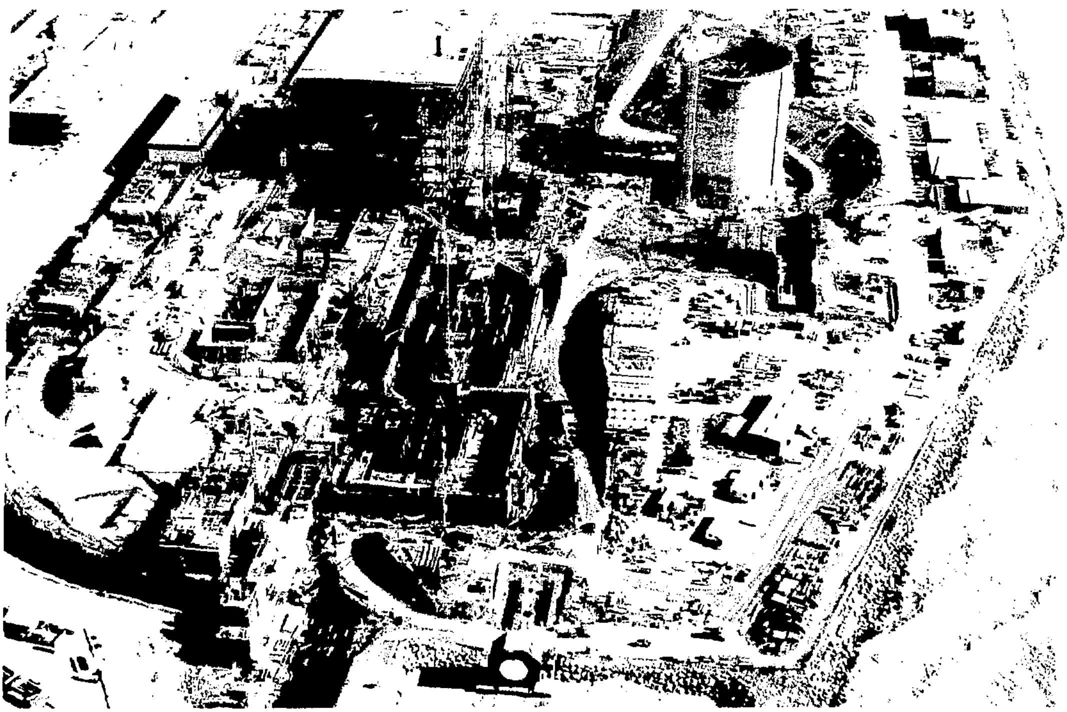


FIGURE 8
DARLINGTON GENERATING STATION

Cost, manpower and in-service date information is shown on Figure 9.

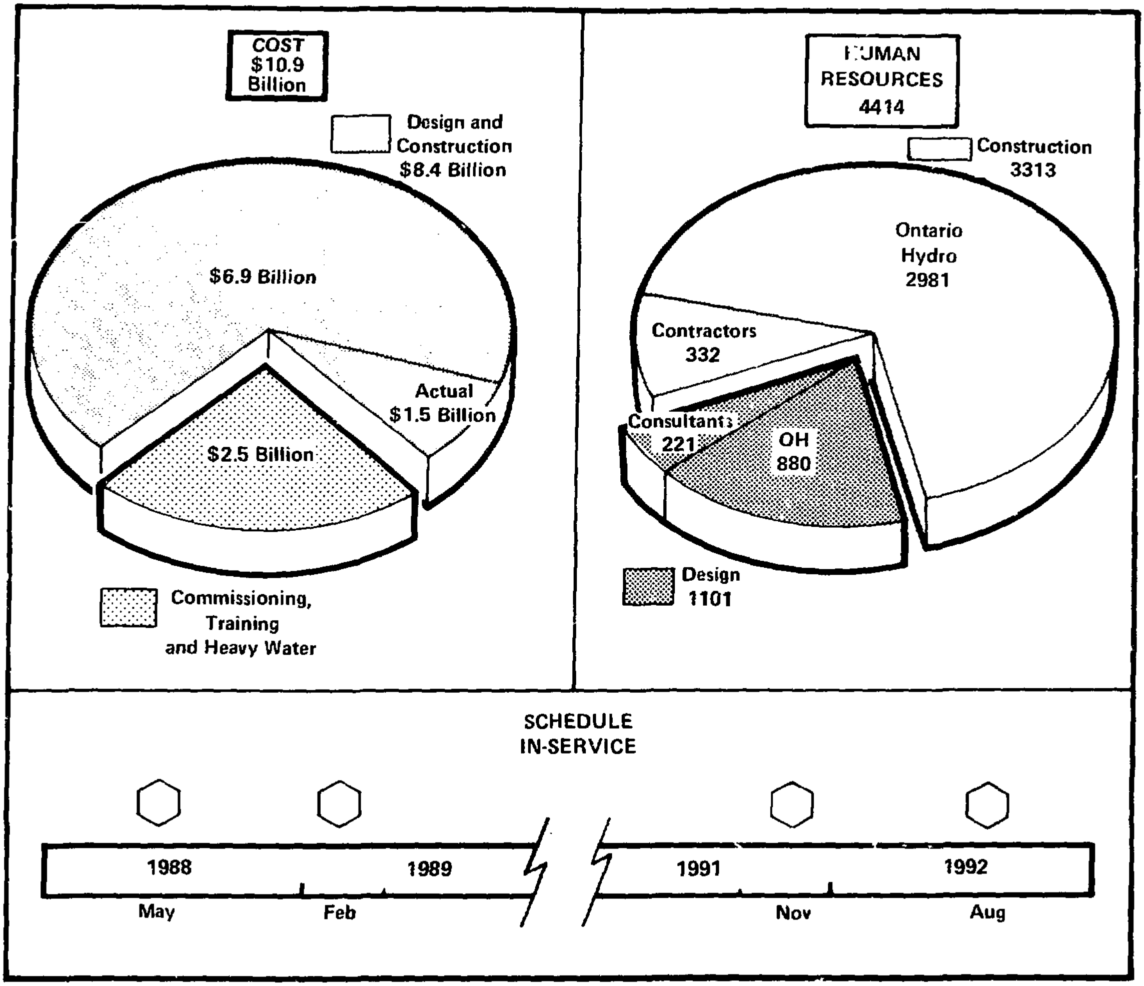


FIGURE 9
DARLINGTON GENERATING STATION
STATUS – MARCH 1984

Type:	CANDU
No. of Units:	4
Unit Size:	881 MW net
Station Size:	3524 MW net

- The cost-pie depicts the make-up of the total project cost and the expenditure status as of March 1984.
- The manpower-pie depicts the make-up of the total project personnel as of March 1984.
- The schedule shows the planned in-service dates of each unit.

Engineering work is proceeding generally on schedule and has reached its peak with a manpower level of about 1,000 (including consultants). Close to 60 per cent of the total engineering work is now complete. Acquisition of equipment and material is well advanced. Purchase orders have been awarded for about $1.9 billion or 80 per cent of the total material required.

The total site manpower presently stands at about 3,200 (including contractors) and will peak at approximately 4,200 in 1985. Work is proceeding generally on schedule.

Some points of special interest with regards to the site progress are as follows:

The first concrete was poured on site in August 1981 and at the end of May 1984, over 330,000 cubic metres have been placed. Work is concentrated on Units 1 and 2 with the first concrete starting on Units 3 and 4 in the spring of 1985.

The total concrete placed so far is about 45 per cent of the total required for the four units.

The 51-metre vacuum building wall was slipformed in September 1983 in 9-1/2 days of continuous concrete pouring.

The first calandria assembly has arrived on site by barge from Montreal and will be installed in the reactor vault during 1984.

The 840-metre water intake tunnel is complete and work is well under way on the 1,850 metres long water discharge tunnel. Diffusers will be incorporated into the discharge tunnel to allow good mixing of the warm discharge water with the lake water. Regulatory requirements limit the temperature to 2°C above ambient temperature.

Full operation of the four units will require 153,000 litres of water per second.

The four individual pumphouses located just north of the station are well under way and all necessary work will be completed to allow flooding of the forebay late in 1985.

The SF_6 switchgear building located north of the CN rail tracks is complete and equipment installation has commenced.

The first steam generator recently arrived on site. The four steam generators per unit will be lifted into each reactor building by a large mobile crane. Installation of the first unit is scheduled for early 1985.

Each steam generator weighs approximately 365 tonnes and will be installed through a temporary construction opening in the reactor building roof. The reactor building is 46 metres high and the boiler will be placed 33 metres from the reactor building wall.

The administration building located just north of the station is nearing completion and the first of the operating staff will be moving in during August 1984.

The new Information Centre, located on a hill just northwest of the station, was completed and went into service on April 2, 1984.

During 1983, Ontario Hydro decided to consolidate tritium removal facilities for Pickering GS and Darlington GS and locate the facility at Darlington. Construction of this facility, as part of the D_2O Management Building, is already under way at Darlington with a planned in-service date of May 1987. The building is located just southwest of the vacuum building.

A related business opportunity is the use of tritium for consumer products. Digital watches, calculators, self-illuminating signs all use tritium as a light source. Last year approximately four million Curies of tritium were used commercially in North America with a market price of about 80 cents per Curie.

Cost Comparison

The costs associated with the design and construction of nuclear units continue to receive close attention both inside and outside of Ontario Hydro. It is interesting to note from Tables 3 and 4 that despite the escalation in regulatory requirements over recent years, the design and construction costs ($/kW excluding interest) and manhours (MHrs/kW) have remained relatively stable for our multi-unit nuclear stations.

TABLE 3
COST DATA FOR NUCLEAR PROJECTS
(1983 $/kW) EXCLUDING INTEREST

Item	Pickering A 2080 MW	Pickering B 2084 MW	Bruce A 2960 MW	Bruce B 3124 MW	Darlington 3524 MW
Total Engineering	149	202	153	168	144
Permanent Material	459	628	487	558	576
Construction	353	411	304	333	381
Design & Construction Subtotal	961	1241	944	1059	1101
Total (See Note 4)	1355	1723	1354	1554	1612

Notes.

1. Total engineering includes hydro, consultant and administration costs.
2. Construction includes hydro and contract direct costs plus total indirect costs.
3. Cost per kilowatt based on net station electrical output.
4. Costs are for the entire capital program associated with a project including commissioning, D_2O, training and known modifications thereto.

November, 1983

TABLE 4
PROJECT MANHOURS PER KILOWATT
NUCLEAR STATIONS

Station	Manhours/kW			
	Engineering	Construction	Commissioning	Total
Pickering A	2.5	10.9	1.1	14.5
Bruce A	2.7	9.7	1.0	13.4
Pickering B	3.8	13.8	1.4	19.0
Bruce B	3.2	11.0	1.0	15.2
Darlington	3.4	12.7	1.3	17.4

Taking the cost comparison one step further, Figures 10 and 11 compare Ontario Hydro design and construction costs and manhours with those of utilities in the United States. The cost data for the US stations was obtained from the Electrical Utility Cost Group (EUCG) and covers units over 500 MW in size. Most of the US utilities are members of EUCG.

These graphs show Ontario Hydro plants have a definite economic edge over their US counterparts.

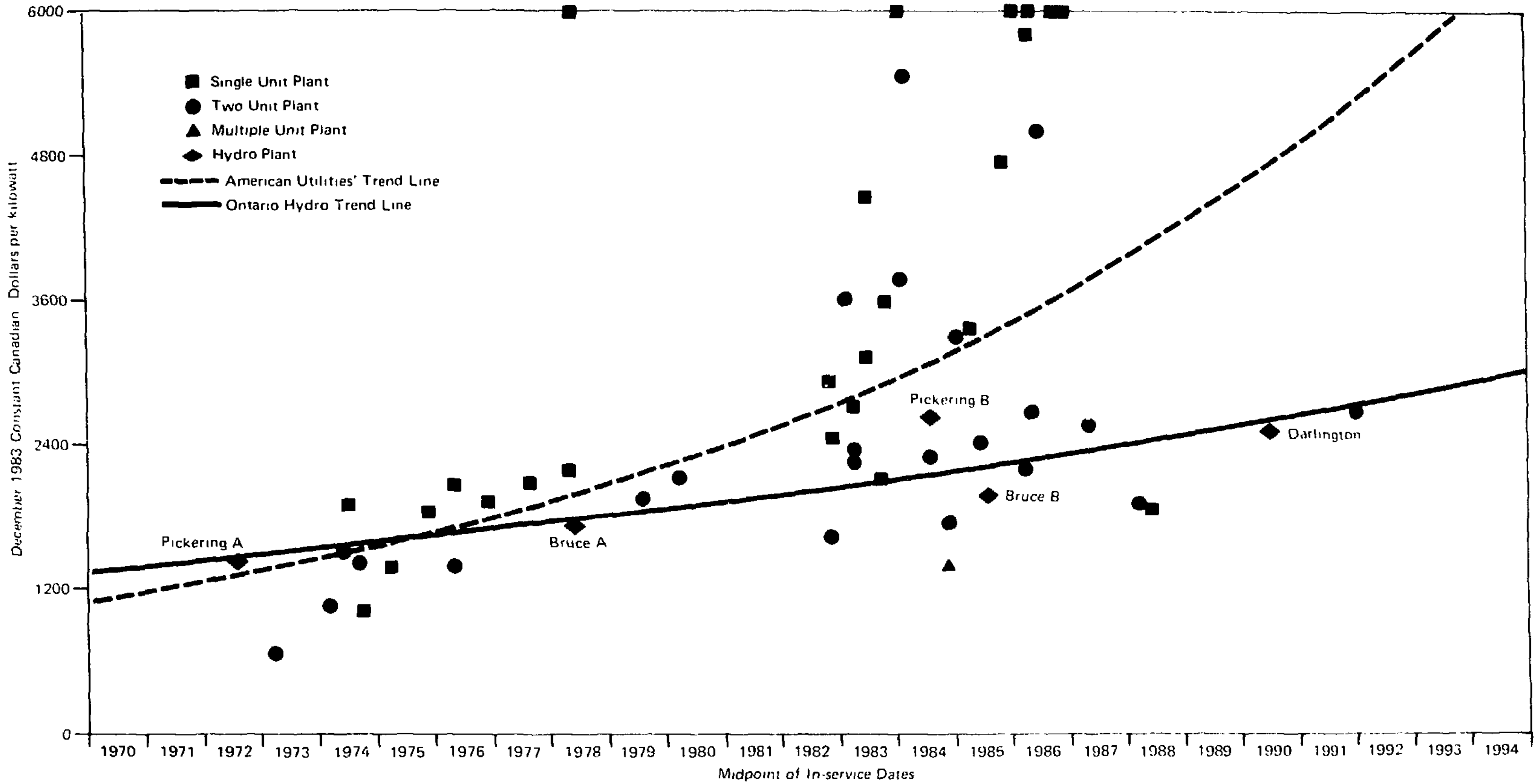
FUTURE PROJECTIONS

Growth in the demand for electricity has declined in recent years. From a historical level of seven per cent per year, we are now predicting a three per cent per year primary load growth between 1983 and 1992. This is some 500 MW higher in 1992 than last year's forecast. Not only has the current recession had a negative effect on load growth, but the high interest and inflation rates have also created an unfavourable climate for financing any new capital intensive long-term project.

Based on these two factors a hold has been put on any commitment for nuclear units after Darlington. During the next decade some 7680 MW of nuclear generating capacity in ten new nuclear units will be added to our system. Although the generation expansion program will be relatively large over the next 10 years, it is expected to undergo major downscaling during this period from three major nuclear stations to one. Extensive work in this period from 1985-1990 is also required for the completion of two additional segments of the 500 kW grid.

During this period the orientation will change from design and construction to supporting the operation of existing capacity for safe, reliable and economic supply of electricity.

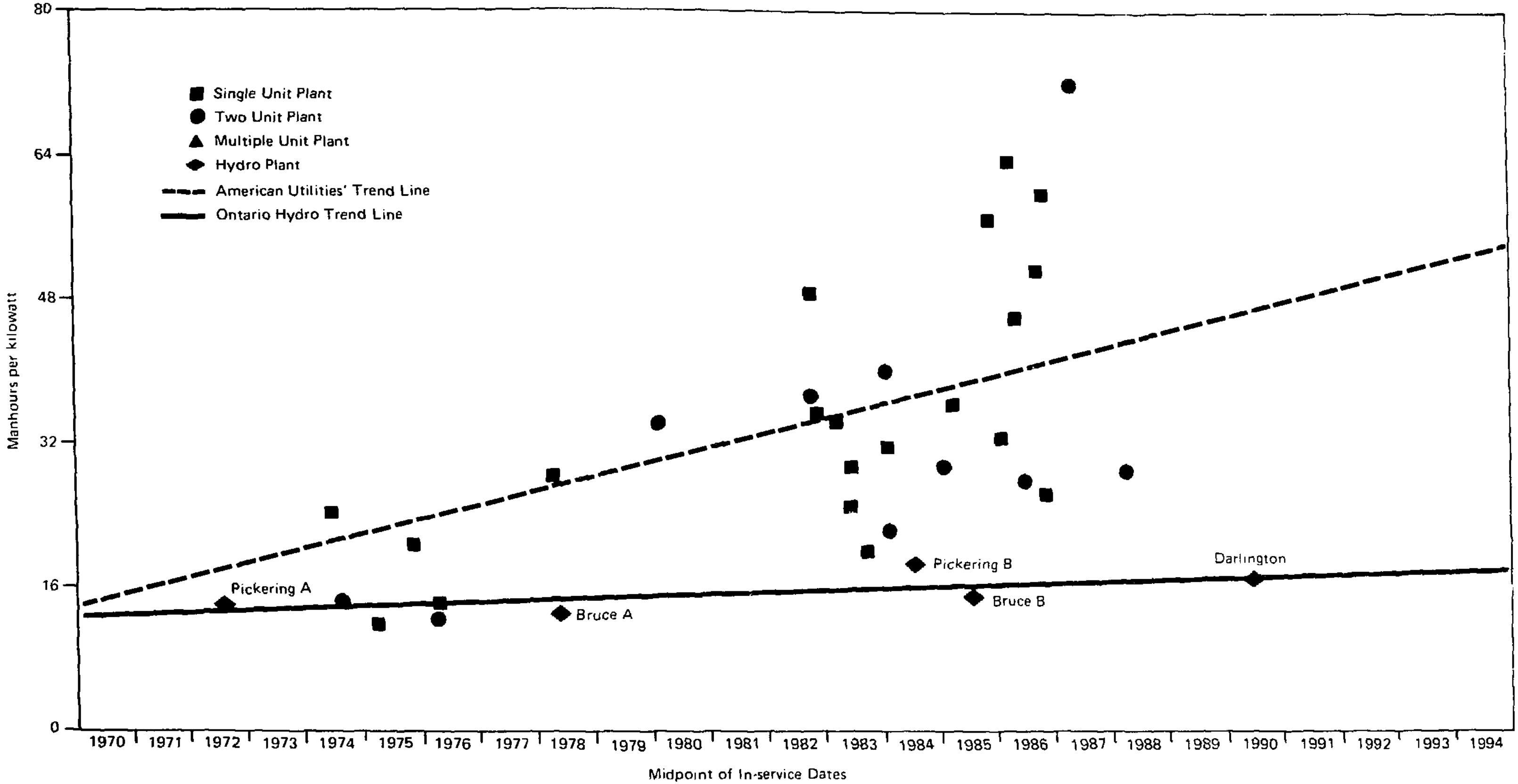
System expansion needs for the second decade 1993 to 2002 are still highly uncertain, and are reviewed annually. Based on current forecasts no new major generating units are expected to be committed for in-service during this period. Supply and demand options, including new nuclear units, will continue to receive attention in meeting the future needs of Ontario Hydro's customers while maintaining a large degree of flexibility to recognize changing circumstances and the long lead times associated with some of these options, especially nuclear generation.



Notes:

1. All plants exclude fuel costs; OH plants also exclude D_2O costs.
2. All plants in Canadian dollars.
3. OH costs include capital modifications and gross commissioning.

FIGURE 10
ELECTRIC UTILITY COST GROUP DATA: NUCLEAR PLANTS
GRAPHIC COMPARISON OF TOTAL PROJECT COST



Notes:

Ontario Hydro data includes manhours for capital modifications and gross commissioning.

FIGURE 11
ELECTRIC UTILITY COST GROUP DATA: NUCLEAR PLANTS
GRAPHIC COMPARISON OF TOTAL PROJECT MANHOURS

Darlington Generating Station Data Units 1 – 4

General

Location	Town of Newcastle, Ontario
Owner, operator	Ontario Hydro
Designers	Ontario Hydro
Number of units in station	Four
Rated output per unit	Generator output 935 MW(e) Self-consumption 54 MW(e) Net electrical 881 MW(e)
Overall net efficiency	31.7%
Fuel	Natural Uranium Dioxide (UO_2)
Moderator	Deuterium Oxide (D_2O-heavy water)
Coolant	Pressurized heavy water
Type	Horizontal pressure tube
Construction	Start of construction late 1977
Schedule	In-service dates: Unit 2 – 1988 Unit 1 – 1989 Unit 3 – 1991 Unit 4 – 1992

Building and structures

Reactor building	
Form	Rectangular
Material	Reinforced concrete
Length	49.8 m (163.4ft.)
Width	28.6 m (93.8 ft.)
Height	51.1 m (167.7 ft.)
Design pressure	–53.1 kPa(g) to +96.5 kPa(g) (–7.7 psi(g) to +14.0 psi(g))
Reactor auxiliary bay	
Form	Rectangular, 5 storey, steel frame, concrete floor & 2 storey concrete basement.
Length	91.2 m (299.2 ft.)
Width	50.65 m (166.2 ft.)
Height	58.2 m (190.9 ft.)
Turbine hall	
Form	Rectangular, steel frame, concrete and grating floor.
Length	91.2 m (299.2 ft.)
Width	54.8 m (180.0 ft.)
Height	44.9 m (147.0 ft.)
Turbine auxiliary bay	
Form	Rectangular, steel frame, concrete and grating floors and basement
Length	91.2 m (299.2 ft.)
Width	18.8 m (61.7 ft.)
Height	45.9 m (150.0 ft.)
Central service area	
Form	Rectangular, steel frame, concrete floors
Length	63.0 m (206.7 ft.)
Width	136.5 m (447.8 ft.)
Height	45.9 m (150.0 ft.)
Powerhouse (Turbine hall & Auxiliary bay & Central service area)	
Overall length	427.8 m (1403.5 ft.)
Overall width	73.6 m (241.7 ft.)
Vacuum Structure	
Form	Cylindrical prestressed concrete
Diameter	48.0 m (157.0 ft.)
Height	70.0 m (230.0 ft.)
Free volume	95 000 m^3 (3.35×10^6 $ft.^3$)
Design pressure	–101.4 kPa(g) to +96.5 kPa(g) (–14.7 psi(g) to +14.0 psi(g))
Location	One at either end of the powerhouse
Length	66.7 m (218.83 ft.)
Width	54.0 m (177.16 ft.)

	Water storage	11,500 m^3 (4.06 x 10^5 ft^3)	*Height*	22.85 m (74.92 ft.)
	Fuelling facilities auxiliary building			
	Form	Rectangular, concrete floors & walls below grade, steel frame with concrete floors above grade.		
Reactor vessels	*Calandria shell*		*Material*	Austenitic stainless steel (filled with steel balls & light water, 60:40 by volume)
	Form	Horizontal, stepped cylinder comprising of main shell, two sub-shells & two annulus plates.		
	Material	Austenitic stainless steel	*Weight (filled)*	2 370 Mg (5,241,000 lb.)
			Length (each)	1 016 mm (3.33 ft.)
	Shell dimensions		*Calandria tubes*	
	Inside diameter	8 458 mm (27.75 ft.)	*Quantity*	480
	Main shell thickness	31.75 mm (1.25 in.)	*Material*	Zircaloy-2, seam welded
	Length	5 981 mm (19.50 ft.)	*Inside diameter*	129 mm (5.077 in.)
	Calandria end shields		*Wall thickness*	1.37 mm (0.054 in.)
	Purpose	Integral with calandria shell, provides support for alignment of fuel channels & shutdown shielding of the reactor faces.		
Reactor core	*Pressure tubes*		*Average reflector thickness at midpoint*	700 mm (27.6 in.)
	Purpose	Fuel channels & primary heat transport	*Fuel load*	6 240 bundles (108 Mg U (237,600 lb. U))
	Quantity	480 tubes (24 x 24 array)		
	Material	Zirconium-Niobium alloy	*Moderator and Reflector D_2O*	312 Mg D_2O (686,400 lb. D_2O)
	Inside diameter	100.0 mm (3.94 in.)	*Maximum channel power*	6.4 MW
	Wall thickness	4.0 mm (0.16 in.)		
	Lattice Pitch	285.8 mm (11.25 in.)	*Average burn-up*	164 MWh per kg. U
			Reactor control	2 digital computers per unit
	Core Radius	3 532 mm (139.06 in.)		
	Core Length	5 944 mm (234.0 in.)		

Reactivity control units	*Shutdown systems*		*Liquid zone control units*	
	Shut-off rods		*Quantity*	14 separate zones
	Purpose	Safety devices to quickly terminate reactor operation	*Type*	Natural water compartments
	Quantity	32 rods	*Orientation*	Vertical
	Type	Stainless steel – cadmium – stainless steel sandwich in the form of a tube	*Reactivity rate of change*	±0.1 mk per sec.
	Orientation	Vertical through lattice	*Reactivity worth*	6.3 mk (full to empty)
	Reactivity worth	- 49 mk within 2.0 sec.	*Control absorber rods*	
	Drive mechanism	Winch & cable driven via an electro magnetic friction clutch by a constant speed induction motor	*Purpose*	Inserted if reactivity rate of change of Liquid Zone Control system inadequate
			Quantity	4 rods
			Type	Same as Shut-off Rods
	Liquid injection shutdown system		*Reactivity rate of change*	±0.1 mk per sec.
	Purpose	Safety system to terminate reactor operation	*Reactivity worth*	−9 mk (inserted)
	Type	Gadolinium nitrate solution	*Adjuster rods*	
	Reactivity worth	- 55 mk	*Purpose*	Normally inserted to limit fuel power: can be withdrawn to provide increased reactivity
	Injection method	Pressurized helium to drive solution into bulk moderator through nozzles	*Quantity*	24 rods
			Type	Stainless steel
	Control systems liquid zone control units		*Reactivity rate of change*	0.04 mk per sec.
	Purpose	Suppress unwanted changes in neutron flux distribution	*Reactivity worth*	+ 17 mk
Moderator	*Type*	Heavy water	*Heat load (max. design)*	139.7 MW (th)
	Total volume	306.3 m^3 (10,818.2 $ft.^3$)		
	Purity	99.75% D_2O by weight		
Primary coolant	*Type*	Pressurized heavy water	*Reactor outlet temperature*	310°C (590°F)
	Quantity	280 Mg (617,290 lb.) at 37.8°C (100°F)	*Reactor outlet header pressure*	*10.0 MPa(a) (1450 psia)*
	Flow per channel (max.)	25.3 kg/s (200,000 lb./hr)	*No. of pumps*	4 per unit
	Reactor inlet coolant temperature	266°C (511°F)		

Steam generators	*Quantity* *Steam pressure at drum (design)* *Steam temp. at drum*	4 per unit 5.068 MPa(a) (735 psia) 264.75°C (508.5°F)	*Total steam output* *Feedwater inlet temp.*	1,310.4 kg/s (10.38 x 10^6 lb./hr) 176.7°C (350°F)
Fuel elements	*Type* *No. per channel* *Diameter of bundle* *Weight of UO_2 per bundle*	37 element bundles, 495 mm (19.5 in.) long 13 bundles 102.49 mm (4.053 in.) 21.36 kg (47.1 lb.)	*Total weight of bundle* *Maximum bundle power (time averaged)*	23.65 kg (52.1 lb.) 787 kW
Turbine generator	*Turbine* *No. of high pressure cylinders* *No. of low pressure cylinders* *Speed*	One tandem compound unit per reactor with external moisture separation and steam reheat (2 stages) 1 double flow 3 double flow 1800 RPM	*Throttle steam press.* *Type of condenser* *Cooling water flow* *Generator* *Rating (0.85% power factor)* *Terminal voltage* *Frequency*	4.83 MPa(g) (700 psig) Two pass 31.6 m^3/sec. (417,392 Igpm) One per turbine 1100 MVA 22 kV 60 Hz
Transformers	*Main output* *Unit service*	12-330,000 kVA, 1 phase, 60 Hz, 21.45/525 kV (3 per unit) 4-80,000 kVa, 3 phase, 60 Hz, 22/13.8/13.8 kV	*System Service*	4-80,000 kVA, 3 phase, 60 Hz, 500/13.8/13.8 kV
Circuit breakers	*500 kV* *13.8 kV*	18 – 2 cycle, 4000 A, 100 kA, SF_6 GIS breakers 154 – 750 MVA, 1200 A and 2000 A	*4.16 kV*	298 – 250 MVA, 1200 A and 2000 A
Standby power	*Combustion turbines*	*4 – 26 MW, 13.8 kV*	*Emergency power generators*	2 – 6.8 MW, 4.16 kV

G&E 1102 February 1984

Pickering Generating Station Data Units 5–8

Location	Pickering Township, Ontario
Owner and operator	Ontario Hydro
Designers	Ontario Hydro and Atomic Energy of Canada Limited
Number of Reactors in plant	Four
Rated output	Gross Thermal Power 1744 MW Gross electrical 540 MW Net electrical 508 MW Self consumption 32 MW
Net efficiency	29.5% overall
Fuel	Natural Uranium Dioxide (UO_2)
Moderator and reflector	Heavy water (D_2O)
Heat Transport Fluid	Pressurized heavy water
Type	Horizontal pressure tube
Construction Schedule	Date of issue of construction license: July 1974
In-service dates	Unit 5 — 1983 Unit 6 and 7 — 1984 Unit 8 — 1985

Buildings and Structures

Reactor buildings (four)

Form	Cylindrical wall with elliptical concrete dome
Material	Reinforced concrete
Design Pressure	6 psig (41.3 kPa)
Internal diameter	140 ft (42.7 m)
Height of cylindrical portion	117 ft (35.7 m)
Dome rise to crown	35 ft 9 inch (10.9 m)
Wall thickness	4 ft (1.2 m)

Reactor auxiliary bay

Form	Two-storey steel frame
Materials (floors)	Reinforced concrete
Length of bay	1 000 ft (304.8 m)

Turbine Hall

Form	Steel frame
Length	1049 ft (319.8 m)
Width	150 ft (45.7 m)
Height	103 ft 7 in (31.5 m)

Turbine auxiliary bay

Form	Steel frame
Length	1068 ft (325.6 m)
Width	60 ft (18.3 m)
Height	124 ft (37.8 m)

Service wing

Form	Two-storey steel frame
Length	335 ft (102 m)
Width	168 ft (51.2 m)

Vacuum building (shared with Unit 1 - 4)

Form	Reinforced concrete cylindrical perimeter wall
Inside diameter	165 ft (50.3 m)
Inside height	166 ft (50.6 m)
Wall thickness	3 ft (914 mm)
Volume (free)	2.9×10^6 ft^3 (8.1×10^4 m^3)
Nominal operating pressure	1.5 psia (10.3 kPa)
Water storage	2 180 000 imp. gallons (9911 m^3)

Administration building

Form	Two-storey masonry

Reactor Vessels

Calandria shell	Horizontal stepped cylinder welded to extensions of end shields
Material	Austenitic stainless steel
Outside diameter	26 ft 6.5 inch (8.09 m)
Plate thickness	1 inch (25.4 mm)
Inside length	19 ft 6 inch (5.94 m)
Calandria shell shields	Austenitic stainless steel slabs 4.5 inch (114 mm) thick
Calandria end shields	Integral with calandria shell Peripheral shell austenitic stainless steel, internal slabs, carbon steel, H_2O cooled
Outside diameter	22 ft 9 inch (6.90 m)
Overall axial length	3 ft 9.5 inch (1.16 m)

Calandria tubes

Quantity	380
Material	Zircaloy-2 seam welded
Inside diameter	4.07 inch (103 mm)
Wall thickness (nominal)	Unit 5: 0.158 inch (4.01 mm) Units 6, 7, 8: 0.160 inch (4.06 mm)

Reactor Physics

Core data

No. of fuel channels	380
Cell array	Approximately octagonal 22 x 22 cells
Lattice pitch	11.25 inch (285.8 mm)
Core radius	149 inch (3787 mm)
Core length	234 inch (5944 mm)
Average reflector thickness at midpoint	26 inch (655 mm)
Fuel load (UO_2)	102.6 megagrams
Moderator system D_2O	265 megagrams (292 short tons) (2.65×10^5 kg)
Heat transport system D_2O (hot)	143 megagrams (158 short tons) (1.43×10^5 kg)

Average thermal flux in fuel	0.52×10^{14} average (0.91×10^{14} max) n/cm^2 sec
Burnup (thermal energy)	232 kg U/unit/day (185 MWh/hg U)
Blanket gas	Helium

Control

Adjuster rods	
Material	Stainless steel (Unit 5) – Cobalt (Units 6, 7, 8)
Purposes	Neutron flux flattening and poison override
Number	21
Orientation	Vertical through lattice
Zone control rods	
Material	H_2O
Purposes	Neutron flux shaping and trim
Number of zones	14
Orientation	Vertical
Control Absorbers	
Material	Cadmium – stainless steel
Purposes	Power reduction
Number	4
Orientation	Vertical
Shut-off rods (SDS1)	
Material	Cadmium – stainless steel
Purposes	Reactor – shutdown
Number	28
Orientation	Vertical
Liquid Injection Shutdown (SDS2)	Concentrated gadolinium nitrate solution is injected into the bulk moderator through six horizontally distributed nozzles on the calandria by opening fast-acting helium pressure valves. The response time of this system is 2 seconds.
Other control features	Addition of natural boron to moderator when xenon poisoning is less than normal, or when there is excess reactivity for other reasons, removed by moderator ion exchange.
Reactor controller	Two digital computers/unit

Moderator

Type	Heavy water
Total volume in core	7760 ft^3 (218 m^3)
Purity	99.75% D_2O by weight
Temperature, maximum	150°F (66°C)
Heat produced in moderator	90 MWth
Flow through Calandria	12 000 igpm (0.9 m^3/s)
Moderator temperature rise	40°F (22°C)

Heat transport fluid

Type	Pressurized heavy water
Quantity	315 400 lbs (143 100 kg)
Total mass flow	65.8×10^6 lbs/hr (8308 kg/s)
Fluid temperature at reactor inlet	480°F (249°C)
At reactor outlet	560°F (293°C)
System pressure at reactor outlet header	1280 psia (8.8 MPa)
No. of pumps	16 (12 active) in 4 groups of 4

Steam Generators

Number	12 in 4 groups of 3
Steam pressure at drum	593 psia (4.1 MPa)
Steam temperature at drum	485°F (251°C)
Total evaporation rate	6.46×10^6 lbs/hr (815 kg/s)
Feed water temperature	340°F (171°C)

Fuel

Type	28 pencil bundles 19.5 inch (495 mm) long
Number per channel	12
Diameter of pencils	0.6 inch (15.2 mm) including Zircaloy-4 sheath
UO_2 pellet diameter	0.564 inch (14.3 mm)
Minimum cladding thickness	0.015 inch (0.38 mm)
Total weight of UO_2 per bundle	43.7 lbs (19.86 kg)
Bundle diameter	4.03 inch (102.4 mm)
Heat transfer area per bundle	7.2 ft^2 (.669 m^2)
Heat flux average	177 000 BTU/ft^2 hr 560 000 W/m^2
Maximum	370 000 BTU/ft^2 hr (1 190 000 W/m^2)
Fuel temperature maximum UO_2	3632°F (2000°C)
Maximum cladding temperature	579°F (304°C)

Turbine Generator

Turbine	One tandem compound unit per reactor with external moisture separation and steam reheat
Number of high-pressure cylinders	1 double flow
Number of low-pressure cylinders	3 double flow
Speed	1800 rpm
Throttle pressure	585 psia (4.03 kPa)
Type of condenser	Single pass
Cooling water flow	313000 igpm (23.7 m^3/s)
Generator	One per turbine – 635 294 kVA, 3 phase, 60 cycle, 24 kV

Transformers

Main power	4 – 575 MVA, 3 phase, 60 cycle, 24/230 kV
Station service unit	4 – 28/36 MVA, 3 phase, 60 cycle, 24/4.16 – 4.16 kV
System	4 – 28/36 MVA, 3 phase, 60 cycle, 230/4.16 – 4.16

Circuit breakers

230 kV	12 – 3 cycle, oil cooled 3000 amp, 23 500 MVA
4.16 kV	256 – 350 MVA, 1200, 2000 and 3000 A

Standby generation and switching

Combustion turbines	6 – 7500 kW, 4.16 kV
Circuit breakers	11 – 4.16 kV, 350 MVA, 1200 and 2000 A

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Bruce Generating Station Data Units 5–8

Location	Bruce Township, Ontario
Owner, operator	Ontario Hydro
Designers	Ontario Hydro and Atomic Energy of Canada Limited
Number of Reactors in Station	Four
Rated outpute per reactor	Generator output 807 MW(e) Self-consumption 57 MW(e) Net electrical 750 MW(e)
Overall net efficiency	31.3%
Fuel	Natural uranium dioxide (UO2)
Moderator	Deuterium oxide (D2O) – heavy water)
Coolant	Pressurized heavy water
Type	Horizontal pressure tube
Construction schedule	Start of construction early 1977 In-service dates: Unit 6 – 1984 Unit 5 – 1984 Unit 7 – 1986 Unit 8 – 1987

Building and Structures

Reactor building

Form	Rectangular
Material	Reinforced concrete
Width	92 ft (28.04 m)
Length	104 (31.7 m)
Height	162.5 ft (49.53 m)

Reactor vault

Length	104 ft (31.7 m)
Height	46.5 ft (14.18 M)
Width	92 ft (28.04 m)
Design pressure	– 7 psig to + 12 psig – 48.3 kPa to + 82.8 kPa
Wall thickness	6 ft (1.83 m)

Reactor auxiliary bay

Form	Rectangular, two-storey steel frame, concrete floors and basement
Length of bay	1426 ft (434.7 m)
Width	150 ft (45.7 m)
Height	48 ft (14.6 m)
Powerhouse	Rectangular, turbine hall and turbine auxiliary bay

Turbine hall

Form	Steel frame, concrete floor, grating floor and basement
Length	1460 ft (445 m)
Width	180 ft (54.86 m)
Height	134 ft (40.8 m)

Turbine auxiliary bay

Length	1460 ft (445 m)
Width	60 ft (18.29 m)
Height	150 ft (45.7 m)

Service building

Form	Rectangular, steel frame, concrete floors
Location	Between units 6 and 7
Length	480 ft (146.3 m)
Width	210 ft (64 m)

Vacuum building

Form	Cylindrical reinforced concrete
Inside diameter	160 ft 6 in (49 m)
Inside height	149 ft (45.4 m)
Wall thickness	3 ft 9 in (1.14 m)
Volume (free)	2.2 x 10^6 ft^3 (62.297 m^3)
Nominal design pressure	+ 7 to – 14 psia
Water storage	2.2 million gallons (10.000 m^3)

Ancillary services building

Form	L-shaped, steel frame, concrete floors
Length	240 ft (73.2 m)
Width	180 ft (54.9 m)

EPS/EWS Building

Length	142 ft (43.28 m)
Width	102 ft (31 m)
Height	29 ft (8.84 m)
Form	L-shaped, steel frame, concrete floors

Reactor Vessels

Calandria shell	Horizontal stepped cylinder comprising main shell, two sub-shells and two annulus plates
Material	Austenitic stainless steel
Main shell inside diameter	27 ft 9 in (8.46 m)
Main shell thickness	1¼ in (3.17 cm)
Total length	19 ft 6 in (5.95 m)
Calandria end shields	Integral with calandria shell, provide support for fuel channels and shielding for the fuelling machine area at the reactor faces
Material	Austenitic stainless steel (filled with steel balls and light water – 60.40 by volume)
Weight (filled)	506 000 lb (229 Mg)
Length (each)	3 ft 6 in (1.06 m)
Calandria tubes quantity	480
Material	Zircaloy – 2 seam welded
Inside diameter	5.077 in (12.9 cm)
Wall thickness	0.054 in (0.137 cm)

Reactor physics

Core data

Number of fuel channels	480
Fuel channel array	24 x 24 square grid
Lattice pitch	11.25 in (0.2858 m)

Core radius	139.1 in (3.532 m)
Core length	234 in (5.944 m)
Average reflector thickness at midpoint	27.4 in (0.696 m)
Fuel laod in reactor	6240 bundles 117 tonne U
Moderator & reflector D_2O	241.1 tonne D_2O
Maximum Westcott flux in fuel (averaged over 830 kW bundle)	1.32×10^{18} n/m$^2 \cdot$ s
Average exist burnup of	165 MW·h/kg (U)

Reactivity control units

Adjuster rods	*Provide additional reactivity to* overcourse Xenon – 135
Arrangement	Shape the power distribution in order to maximize power output three vertical banks each with 8 adjuster rods
Reactivity worth (nominal)	– 17.5 mk
Zone control units	Suppress unwanted changes in flux distribution, provide *operating control of reactivity* in 14 separate zones in the *reactor*
Number of zones	14
Orientation	Vertical
Reactivity insertion rate (maximum for 24 units)	± 0.115 mk/s
Mechanical control absorbers	Inserted whenever reactivity *depth or rate of light water zone* control system is inadequate
Quantity	4
Reactivity worth	– 9.5 mk

Reactor shutdown devices

Shut-off rods	Safety devices to quickly terminate reactor operation
Quantity	*32*
Type	Stainless steel – cadmium – stainless steel sandwich in the *form of a tube*
Orientation	Vertical through lattice
Reactivity insertion	– 49 ± 2 mk within 2 sec. with 2 rods out of service
Poison injection nozzles	Safety devices to quickly terminate reactor operation
Quantity	8
Liquid poison	Gadolinium nitrate
Reactivity depth	> – 300 mk with one nozzle out of service

Moderator

Type	Heavy water
Total volume	10 818.1 ft^3 (306.3 m^3)
Purity	99.75% D_2O by weight
Heat load (maximum design)	147 MW (th)

Primary Coolant

Type	Pressurized heavy water
Quantity	660 630 lb (300 Mg) at 100 F (37.8 C)
Flow per channel (nominal)	189 000 lbs/hr (23.8 kg/s)
Reactor inlet coolant temperature (inner zone)	483 F (250 C)
Reactor outlet temperature	581°F (306°C)
Reactor outlet header pressure	1350 psia (9.31 MPa (a))
Number of pumps	4

Boilers

Quantity	8 per unit
Steam pressure at drum (design)	620 psig (4.27 MPa (g))
Steam temperature at drum	492°F (256°C)
Total steam output	10.4×10^6 lb/hr (for 8 boilers)
Feedwater inlet temperature (including reheater drains)	476°F (247°C)

Preheaters

Quantity	4 per Unit
Feedwater inlet temperature	340°F (171°C)
Feedwater outlet temperature	477°F (274°C)
Feedwater flow	9.954×10^6 lbs/hr

Fuel Elements

Number of elements	37
Number per channel	13
Number in reactor	6240
Weight of UO_2 per bundle	21.3 kg
Total weight of bundle	23.6 kg
Length	0.495 m
Diameter of bundle (max)	102.74 mm
Maximum outer element surface heat flux	1352 kW/m^2

Turbine Generator

Turbine	One tandem compound unit per reactor with external moisture separation and two stages of steam reheat
Number of high-pressure cylinders	1
Number of low-pressure cylinders	3
Speed	1800 rpm
Throttle steam pressure	600 psig (4.13 MPa (g))
Type of condenser	Single pass
Cooling water flow	550 700 Igpm (41 700 L/s)
Generator	One per turbine
Rating (90% power factor)	960 MVA
Terminal voltage	24 kV
Frequency	60 Hz
Power output (gross)	807 MW (e)

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