Appendix 1 Comparison of Bruce A, Bruce B and Darlington

1.1 Introduction

An overview of the differences between Bruce A, Bruce B and Darlington A has been made, concentrating on the nuclear portions of the designs. An overview of the difference between Bruce A and B is also given. Generally, differences between stations arise since the industry is on a learning curve. The equipment suppliers, the designers and the regulatory agencies all contribute their share of progressive and retro-grade changes. All of the difference outline below are a result of this phenomenon.

1.2 The two zone design decision

Prior to the design of Bruce A, no power reactor in operation experienced boiling in the primary heat transport system (except for a brief period at NDP during an experimental stage). The two zone system for Bruce A was therefore devised to increase the heat transfer in high power fuel channels without experiencing boiling, increasing the system pressure, increasing channel flow, or boiler area; channel flow was limited to 190,000 lbm/hr. As illustrated in Figure 1, to increase the heat transfer using a single zone system required lowering the RIH temperature (increased steam generator area) raising the ROH temperature (i.e., increasing ROH pressure), permitting HTS boiling, lowering steam drum pressure and hence temperature, or some combination of the above. Boiling was not permitted in the HTS. The ROH pressure could not be raised without incurring a burnup penalty due to increased pressure tube thickness. The secondary side conditions could not be changed without an efficiency penalty and an increased turbine cost due to the larger size resulting from lower pressures. This left the one possibility of lowering the RIH temperature. This is not possible in a single zone system without increasing the boiler area, given the above constraints. The 2 zone system evolved, therefore, as a means to lower the RIH temperature of those channels in the centre of the core (inner zone) which nominally have a higher power rating than the outer channels (outer zone).

This was achieved by dividing the D_2O from the boilers into 2 parts: one cooled by the preheater and one bypassing the preheater (see Figures 1 and 2). This bypass flow is thus hotter than the preheater outlet flow. The bypass flow supplies the outer zone and the preheater flow supplies the inner zone. Thus, boiling is prevented in all channels.

At a later date, the reactor power was uprated and, as a result, some boiling occurs in some outer zone channels. This was judged acceptable based on increased confidence of boiling gained in the interim. However, no net boiling was predicted for the ROH.

1.3 Ramifications of the two-zone system

The above design decision to go to the 2 zone system led to the majority of difference between Bruce and Darlington. At the time of the Darlington A design, confidence of a boiling design was already expressed in the 600 MW(e) design. Hence, Darlington A heat transport system design was based on the 600 MW(e) concept even though the reactor was basically that of Bruce. This meant that boiling, resulting in up to 4% quality at the ROH was permitted and that a single zone was adequate.

Separate Preheaters vs. Integral Preheaters

The Bruce concept dictated that the preheater and the boiler be separated to permit a preheater D_2O bypass flow. Thus, Bruce has separate preheaters while Darlington has integral preheaters. The feedwater train routing, number of valves and control design for each plant reflects this difference.

Process Piping

The PHT piping is different to reflect the pipe routing requirements as shown in figures 8.4 and 8.6.

PHT Pumps and Motors - Trimmed Flow

The PHT pumps of Bruce are larger than those of Darlington since full flow is needed for the outer zone channels at Bruce; all channels at Bruce have the same design flow. Trimmed flow is used at Darlington since the inlet temperature is constant for all channels; only enough flow is provided to match the power input of that channel to give a constant enthalpy rise for all channels.

Pressurizer Size

..e pressurizer size needed for the boiling core of Darlington is 2247 ft^3 compared to 1200 ft^3 of Bruce. The extra volume is required to meet the increased swell and shrink needs resulting from increased void formation and collapse.

Shutdown Cooling System

The separate preheater of Bruce allowed their use in a Shutdown Cooling System. However, full PHT inventory and normal PHT circulation are required for its operation. A separate Maintenance Cooling System is required for maintenance requiring partial draining of the heat transport system (pumps, steam generators, etc.). However, Darlington A has a system similar to the maintenance cooling system at Bruce, but called the Shutdown Cooling System, which is used for both shutdown and maintenance cooling.

1.4 Boiler size considerations

The state of the art in boiler design dictated that eight boilers be used at Bruce. Larger boilers were deemed feasible by the time of the Darlington A design and four integral preheater "light bulb" type steam generators were chosen.

1.5 One vs. two loops

Also following the state of the art thinking on safety concepts and environmental regulations, the two loop concept, as per the 600 MW(e) design, was chosen for Darlington. This limits the building overpressure upon a loss of primary coolant and prevents fuel failures in the unfailed loop. The single loop concept was considered adequate at the time of the Bruce design. This single loop design can lead to reverse flow through a failed pump, unlike the two loop concept.

1.6 Process optimization

For Darlington design, an optimization computer code was available which was not available for the Bruce design. Consequently, the flows, temperatures and pressures of both designs are different.

Darlington was optimized to generally higher values of the main process parameters compared to Bruce, as shown in Table 8.1. Initially the channel flows limit for Darlington was, as per Bruce, 190,000 lb_m/hr. Measurements at Bruce A G.S., however, showed that some channels were operating in excess of 200,000 lb_m/hr and the Darlington figures has since been updated for 200,000 lb_m/hr with a resulting drop in ROH quality from 4% to 2%.

1.7 Boosters vs. adjusters

The Bruce A design uses boosters for reactivity insertion during poison over-ride whereas all subsequent reactors use adjusters. This reflects a reassessment of the Bruce A experience from points of view of economics, safety and complexity.

1.8 Magnetic filters

Advances in magnetic filter design prompted the use of these filters on Darlington to augment PHT purification and to reduce the heat loss due to purification. However, experience at Bruce A indicates reduced purification flow requirements and, hence, the magnetic filters may not be economical.

1.9 Process control

In the area of process control, Bruce A was designed with digital control for the Reactor Regulating System, the Demand Power Routine, the Unit Power Regulator and the Boiler Pressure Control. Analogue control is used for the Boiler Level Control and the Pressure and Inventory Control. Current thinking on Darlington A is to incorporate all control functions into the main computer as digital controllers. This gives greater flexibility for generating enhanced control routines if desired or needed after commissioning and is cost effective if a main computer is being used in any case.

1.10 Separate vs. common steam drum

Because of difficulties being experienced at Pickering A in drum level control of the 16 separate drums, a common drum for a bank of four boilers was chosen for Bruce A. Experience gained in the interim plus the fact that Darlington only has 4 steam generators led to the decision to have a separate drum for each boiler.

1.11 Seismic considerations

Darlington A was designed to more stringent seismic requirements than Bruce A. The Bruce A concept of hanging the boilers from the fixed drum and also hanging the preheaters, allowed for flexibility for thermally induced motion. Seismic snubber requirements were not stringent and hence the cost was acceptable. The more stringent requirements for Darlington A and the fact that a common drum was not available for support led to fixed boilers and pumps plus an expansion loop in the primary pump suction line.

1.12 Critical heat flux

Bruce A was designed at AECL based on a critical heat flux correlation as developed by Krishnan, the Krishnan Lower Bound Correlation, for 37-Element fuel bundles.

A critical power ratio limit of 1.29 was set as the design criterion. For Darlington A, the design criteria set by Ontario Hydro was a 10% improvement on the Lower Bound Correlation but with a CPR limit of 1.39; this is presently susceptible to a redefinition pending the outcome of the recent tests on 37-Element fuel at CRNL and Westinghouse (Canada).

1.13 Differences between Bruce A and Bruce B

Operating and Design Pressures

Bruce A trip set point is 70 psi above normal operating pressure, whereas the Bruce B reactor trip set point is 100 psi above normal operating pressure. The Bruce B value will reduce the incidence of spurious trips.

The Bruce A relief valve set point is 50 psi above normal operating pressure, whereas the Bruce B relief valve set point is 80 psi above the normal operating pressure to reduce the incidence of spurious operation.

Bruce B has an outlet header operating pressure 18 psi above the Bruce A value. This is the highest pressure practical without changing pressure tube thickness. This has a small benefit on CPR.

Preheater Design

The preheater internals for Bruce B were strengthened and the preheater bypass and rupture disc eliminated. This is to eliminate the possibility of excessive damage to the preheater internals due to certain secondary side line failures.

Steam Generator Design

The Bruce A arrangement consists of a cross-drum design with a common drum serving four steam generators. Warm-up and cooldown rates were severely limited by high stress levels in the Tee-Junction area.

The Bruce B arrangement consists of integral steam drums for each steam generator which permits warm-up and cooldown at the design rate.

Seismic Design

On Bruce A all nuclear structures were analyzed on the basis of a dynamic analysis in both the horizontal and vertical directions based on the maximum hypothetical earthquake that can be expected at or near the Bruce A site.

On Bruce B all structures, components and systems are seismically qualified. Two levels of earthquake are defined. The design basis earthquake (DBE) and the site design earthquake (SDE). In addition, three categories of qualification are defined. Category A systems must retain their pressure boundary integrity or structural integrity during and following the specified earthquake. Category B systems must retain their pressure boundary and remain operating (or operable) during and/or after the specified earthquake. Category C systems must retain their pressure boundary integrity during and after and be operable after the specified earthquake.

Heat Transport 'Pump' Design

The Bruce B pumps are equipped with an auxiliary impeller that assure adequate flow to the hydrostatic bearings during both forward and reverse turbining conditions. The Bruce A arrangement depended on the pump discharge pressure being higher than the pump suction pressure (i.e., forward rotation only). The pump feet strength are significantly higher on Bruce B due to the higher postulated burst pipe loads.

Heat Transport Pump 'Motor' Design

The solid flywheel was eliminated on Bruce B to reduce inspection requirements and ease motor disassembly. Bruce B has an improved brake. The Bruce A brake restricts operation under certain conditions. Improved bearing design on Bruce B is incorporated to give better acceptability and to maintain adequate lubrication during reverse rotation.

Fuel Channel Assembly Design

Several detailed design changes were made on Bruce B to accommodate the effects of axial creep.

Feeder Design

Several changes were made to the Bruce B feeder design to accommodate fuel channel creep.

Feedwater Control

With the independent steam generators on Bruce B, the feedwater control to each steam generator must be regulated. Trim valves are provided in the feed line to each steam generator downstream of the preheaters.

Table 8.7 Main Process Parameters and Features

Parameter	Bruce A	Bruce B	Darl. A	Darl.A Revised
ROH pressure	1332	1350	1450	1450
ROH Temperature °F	579	579	591	591
ROH Quality %	.08	.08	3.8	2.0
RIH Temperature °F	509/483	509/483	509	509
Maximum Channel Flow	190,000	190,000	190,000	200,000
# of channels	480	480	480	480
# of pumps	4	4	4	4
# of steam generators	8	8	4	4
# of preheaters	4	4	4	4
Type of preheater	separate	separate	integral	integral
# of Zones	2	2	1	1
# of Loops	1	1	2	2
Channel Flow Type	not trimmed	not trimmed	trimmed	trimmed
Power Output	750	750	850	850
	(balance to BHWP)	(Balance to BHWP)		
PHT Pump Size	9,100 (Hot)	9,100 (Hot)	8,133 (Hot)	8,133 (Hot)
Pressurizer Volume (ft^3)	1200	1200	2247	2247

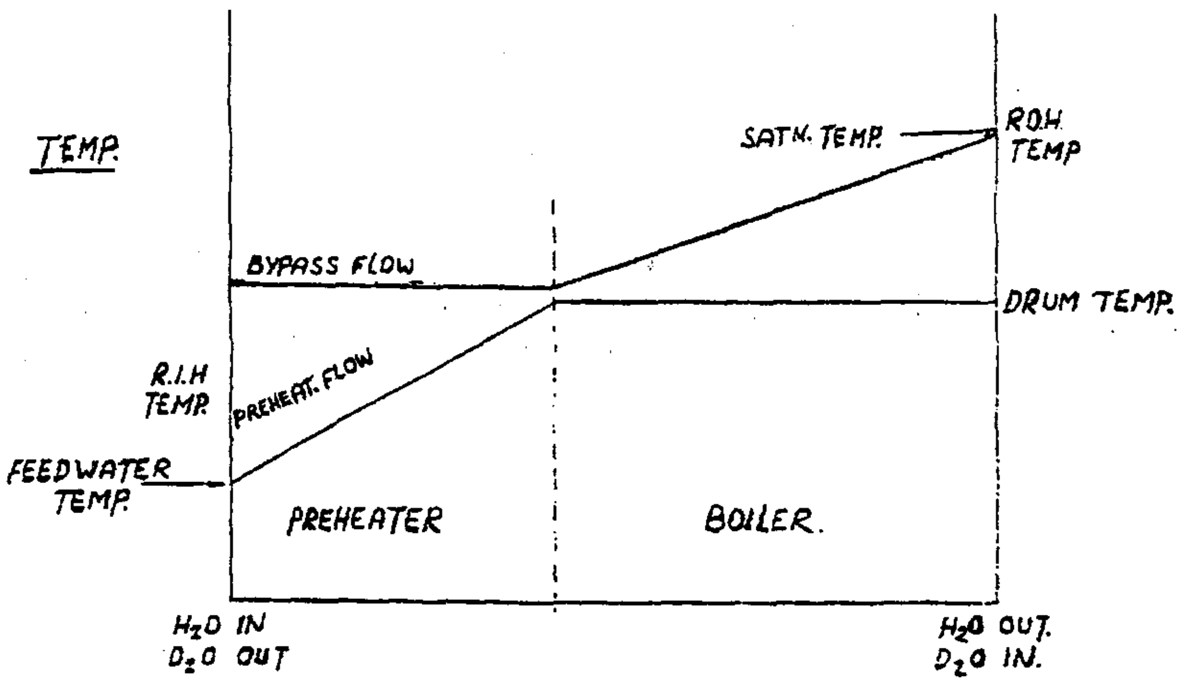

Figure A1.1 Bruce heat duty diagram