Turbine, Generator & Auxiliaries - Course 234
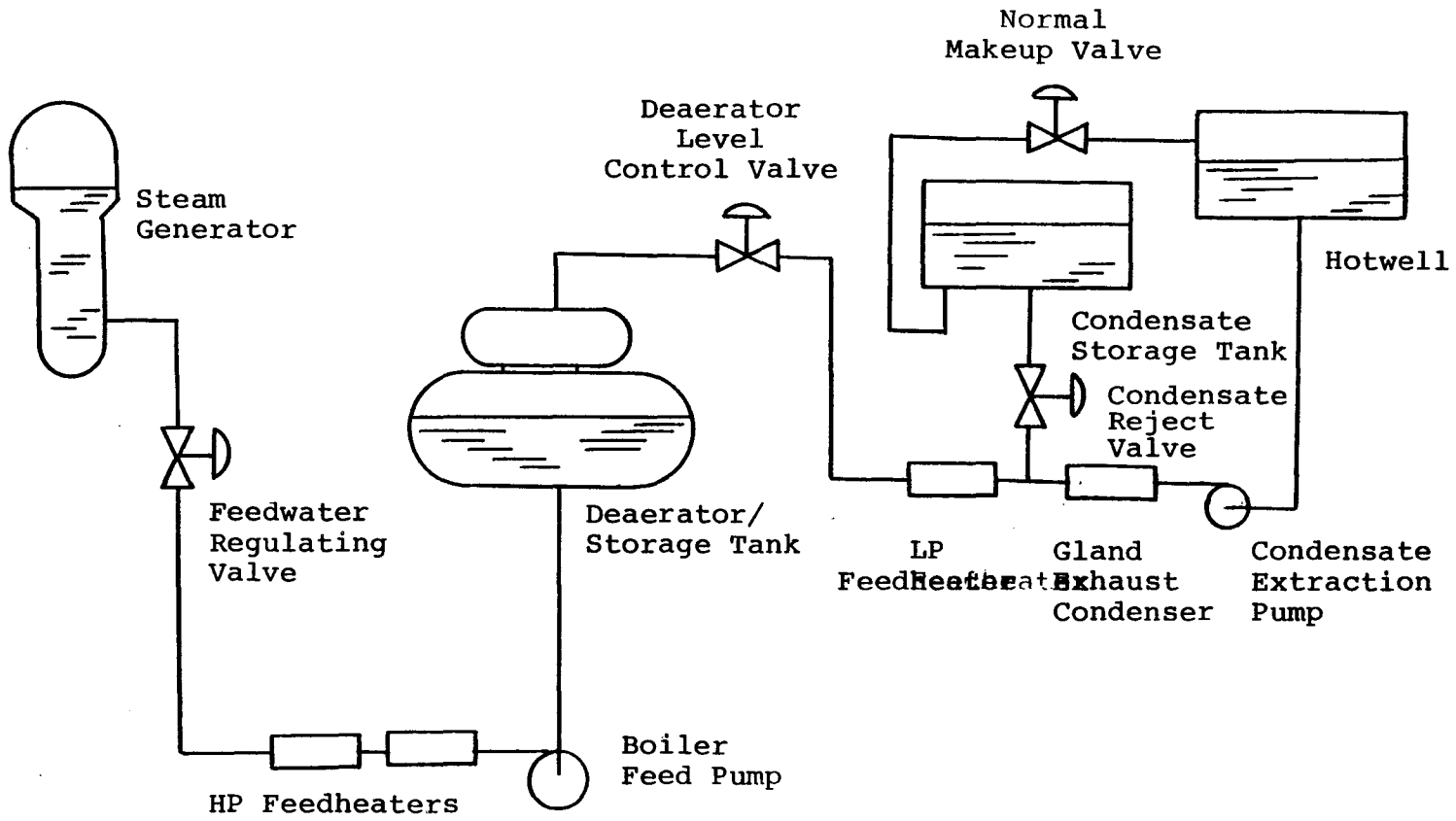
FEEDWATER CONTROL AND OPERATION

The feedwater system must be capable of delivering to the steam generator the proper quantity of heated feedwater for all power levels. Since the quantity of water stored within the system (primarily in the steam generators, deaerator and hotwells) is rather limited, there is a necessity for the system to maintain a strictly controlled water inventory and to be able to rapidly respond to changes in feedwater demand.

The water inventory in the feedwater system is maintained by controlling the level in the steam generators, deaerator storage tank and hotwells. Figure 7.1 shows the level control valves associated with the feedwater system of a large nuclear generating station. As a starting point we will discuss level control in each of the three vessels and then discuss the overall operation of the system.
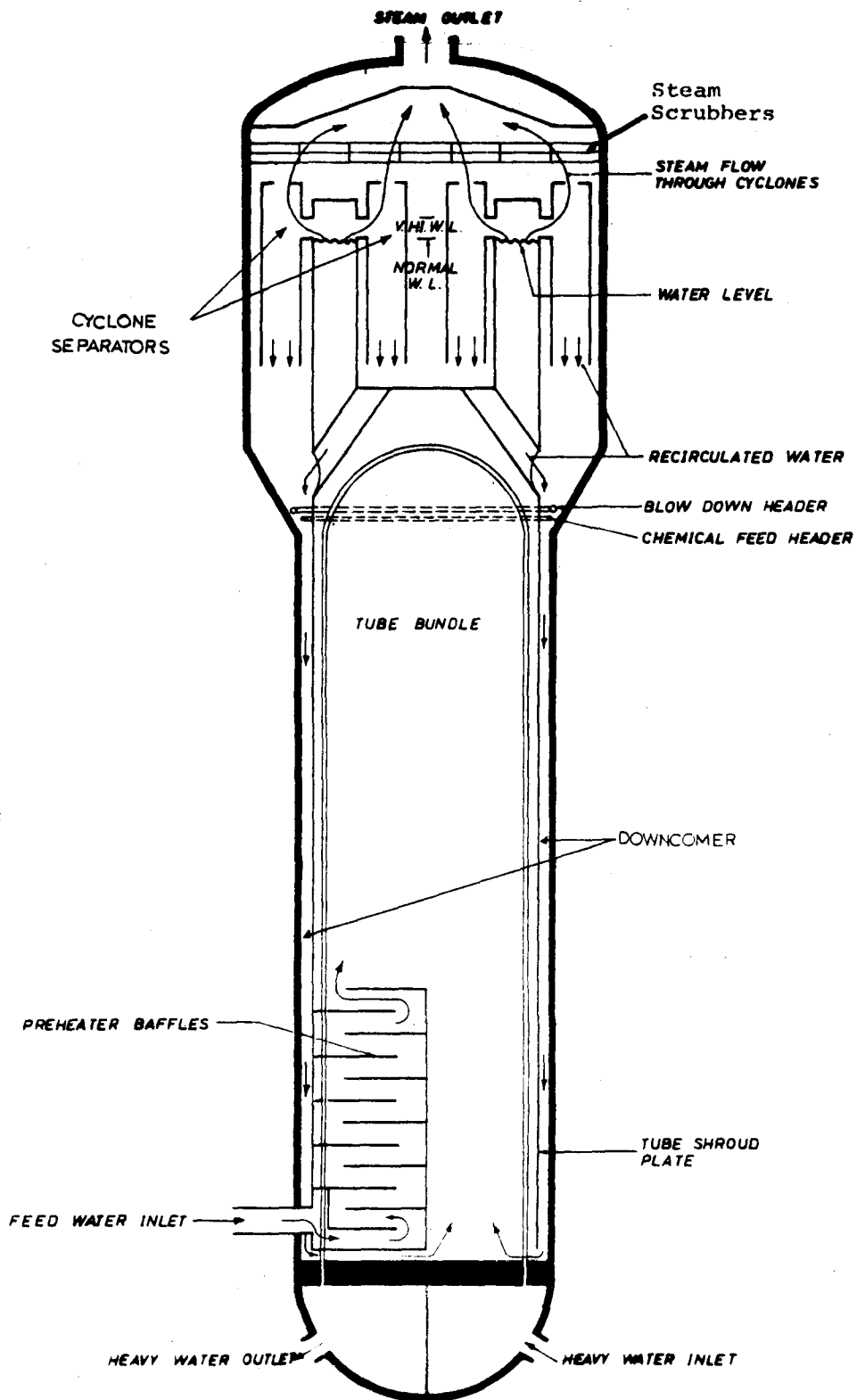
Steam Generator Level Control

It is impossible to discuss steam generator level control without including a discussion of swell and shrink as it relates to the steam generators. Swell is a transient increase in boiler level which accompanies a rapid increase in steam flow; shrink is a transient decrease in boiler level which accompanies a rapid decrease in steam flow. If the steam flow from a steam generator (Figure 7.2) increases, the pressure in the steam generator drops. This results in flashing of water to steam in the tube bundle (riser) section of the steam generator. This increase in volume in the tube bundle forces water to back up the downcomer and, since downcomer level is what is measured as steam generator level, this results in an upswelling of boiler level which is called swell. On a down power transient, the pressure in the steam generator increases. This results in a collapsing of steam bubbles in the tube bundle. This decrease in volume in the tube bundle causes a drop in downcomer level which is called shrink.

The magnitude of swell and shrink depends on the size and rate of the power change: the greater the size and rate of change of steam flow, the greater the resultant swell or shrink. If the change is slow enough there may be no apparent swell or shrink. Figure 7.3 shows the effect of swell and shrink from a rapid power change of 50% of the maximum continuous rating for a generator with a constant level program (level which feedwater regulating valves attempt to maintain does not change).
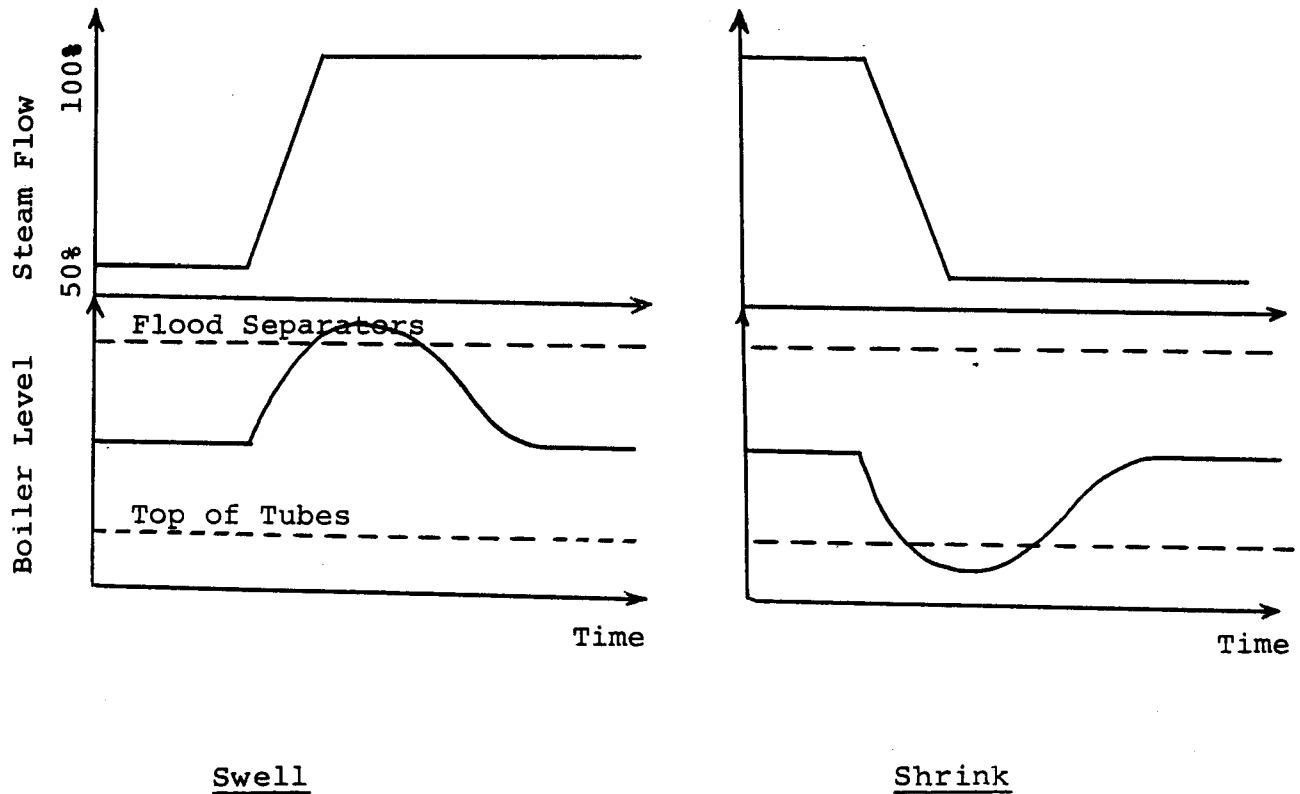
Normal
Makeup Valve

Deaerator
Level
Control Valve

Hotwell

Steam
Generator

Condensate
Storage Tank

Condensate
Reject
Valve

Feedwater
Regulating
Valve

Deaerator/
Storage Tank

LP
FeedHeaterheaterExhaust
Condenser

Gland
Exhaust

Condensate
Extraction
Pump

Boiler
Feed Pump

HP Feedheaters

Feed System Control Valves

Figure 7.1

STEAM OUTLET

Steam
Scrubbers

STEAM FLOW
THROUGH CYCLONES

V.HI.W.L.

NORMAL
W.L.

WATER LEVEL

CYCLONE
SEPARATORS

RECIRCULATED WATER

BLOW DOWN HEADER

CHEMICAL FEED HEADER

TUBE BUNDLE

DOWNCOMER

PREHEATER BAFFLES

TUBE SHROUD
PLATE

FEED WATER INLET

HEAVY WATER OUTLET

HEAVY WATER INLET

Steam Generator

Figure 7.2

Swell and Shrink (Constant Level Program)
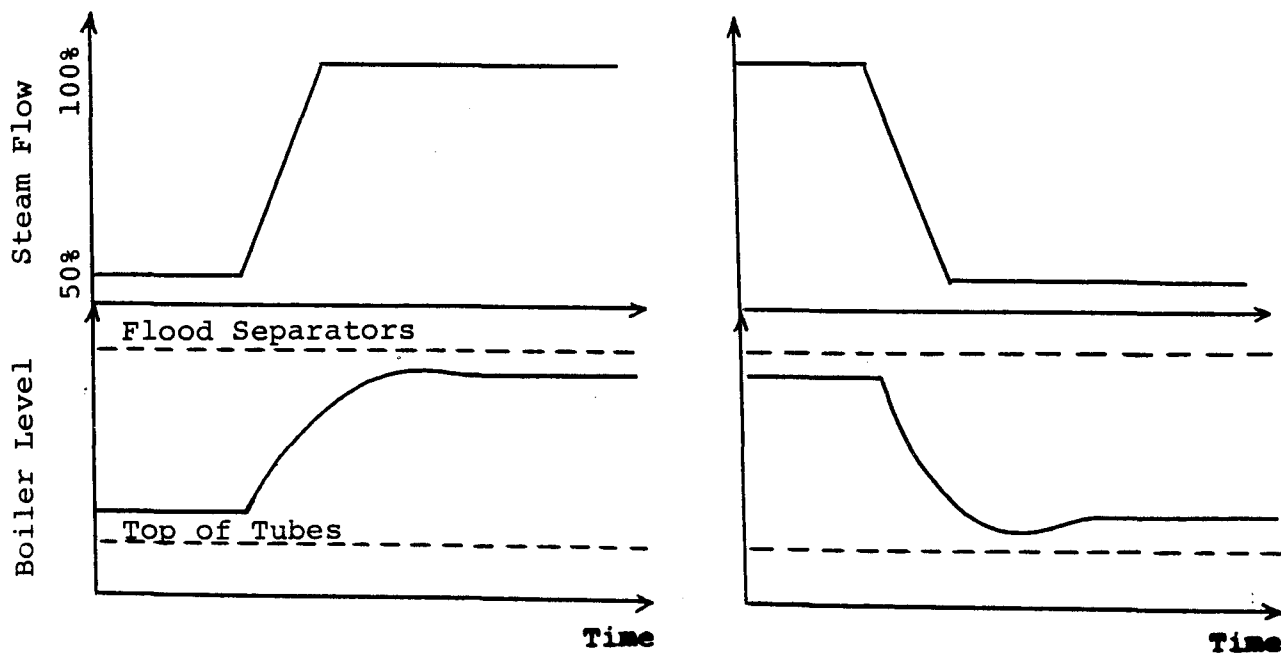
Figure 7.3

Steam generator level must be held within fairly close limits to keep from flooding the separators on the high end and to keep from uncovering the tubes on the low end. To prevent swell or shrink from causing an out of specification boiler level, the operating level is programmed to accommodate swell and shrink. The programmed level is low at low power levels to allow room for swell in the event of a fast power increase (safety valves open, steam reject valves open). At high power level, the programmed level is high to accommodate shrink in the event of a fast power decrease (turbine trip, load rejection).
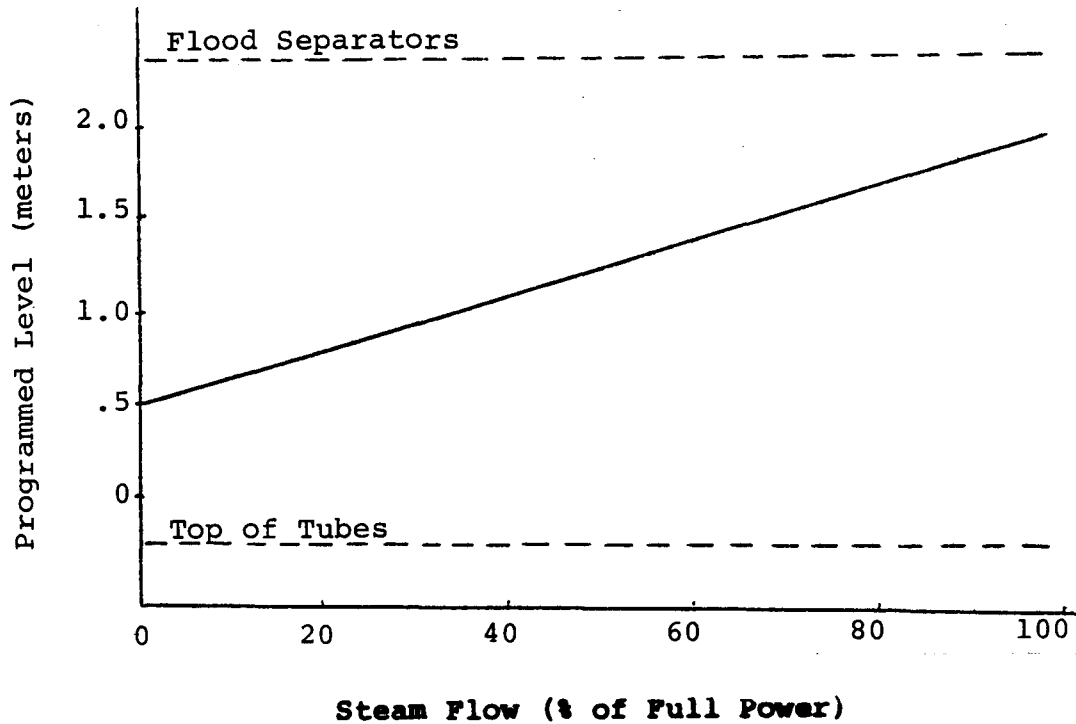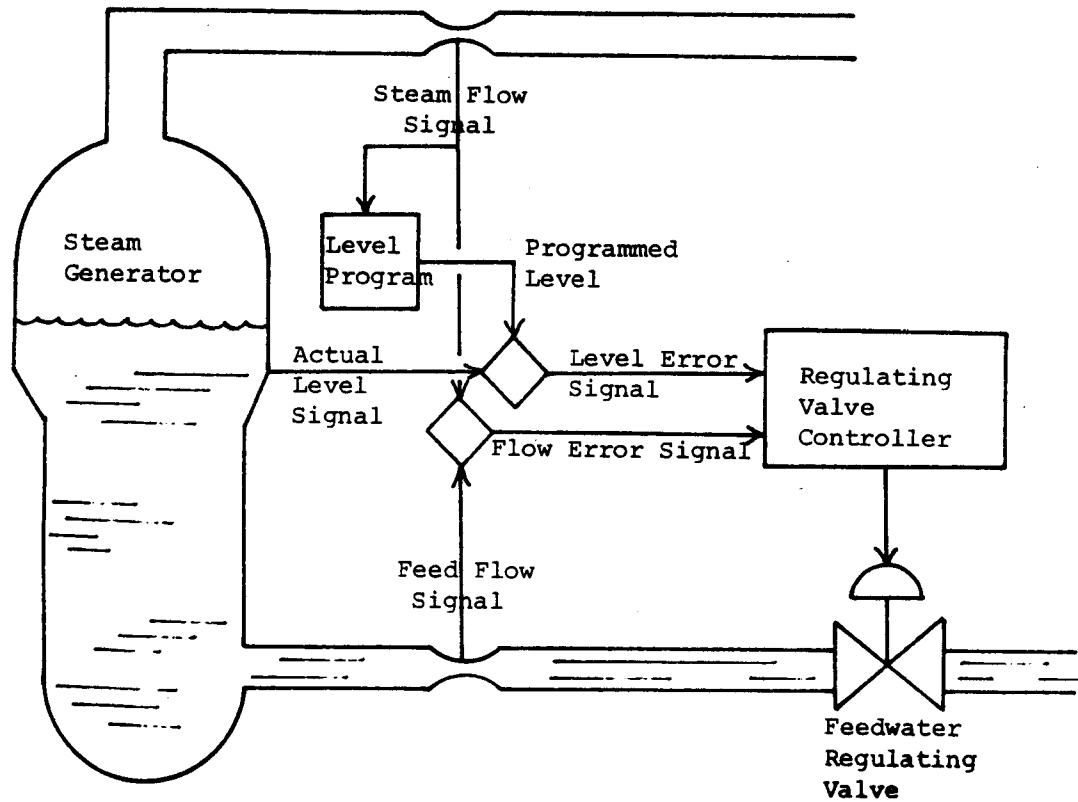
Programmed Boiler Level

Figure 7.4

Figure 7.4 shows the level program for a typical large CANDU generating station. As steam flow increases from 0% to 100% of full power, the level program increases from .5 meters to 1.9 meters above the reference point (the location of the zero level reference point is somewhat arbitrary but corresponds approximately to the top of the tube bundle). Figure 7.5 shows the effect of swell and shrink in a steam generator with this type of level program. By comparing this with Figure 7.3 you can see the benefit of this type of level programming.

Swell and Shrink (Ramped Level Program)

Figure 7.5

The water level in the steam generators is regulated by
the feedwater regulating valves. These valves are controlled
by three variable parameters: steam generator level, steam
flow and feedwater flow. Figure 7.6 shows a block diagram of
feedwater regulating valve control.

Feedwater Regulating Valve Control

Figure 7.6

Steam flow is used to derive the programmed level in the steam generator (programmed level is proportional to power level). The actual steam generator level is compared with the programmed level and a "level error" signal is developed: actual level greater than programmed level shuts the feed-water regulating valve; actual level less than programmed level opens the feedwater regulating valve. At the same time steam flow is compared to feed flow and a "flow error" signal is developed: steam flow greater than feed flow opens the feedwater regulating valve; feed flow greater than steam flow shuts the feedwater regulating valve. It is the algebraic sum of the level error and flow error signals which determine the direction and magnitude of feedwater regulating valve movement.

The operation of the feedwater regulating valve on an increase in power level (steam flow) is shown in Figure 7.7. During normal power level changes the rate is slow enough that swell and shrink effects are not seen.

(a) Governor steam valves open;

(b) Steam flow increases (steam flow greater than feed flow)
     and develops flow error signal;

(c) Programmed level increases (actual level less than pro-
     grammed level) and develops level error signal;

(d) Both (b) and (c) act to open the feedwater regulating
     valve admitting more feedwater to the boiler;

(e) Feed flow rises above steam flow and level in boiler
     starts to increase;

(f) When actual level equals programmed level, the feedwater
     regulating valve closes partially so that feed flow
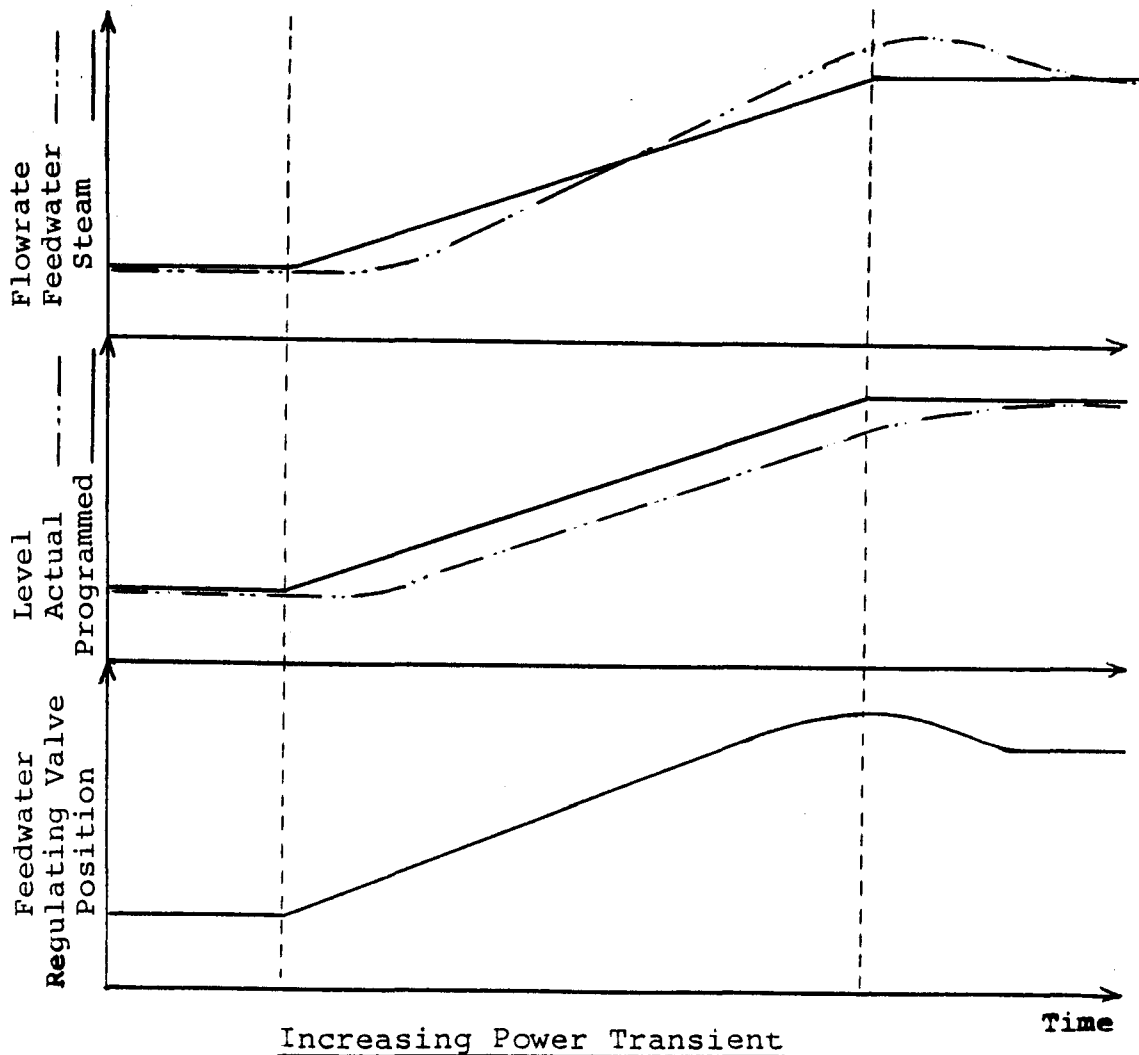   matches steam flow.

Increasing Power Transient

Figure 7.7

Deaerator Storage Tank Level Control

The deaerator storage tank is the primary inventory of feedwater within the feed system. The level in the deaerator storage tank is controlled between 2.75 meters and 3.00 meters. The condensate flow to the deaerator is regulated by the deaerator level control valves (usually three 50% valves or two 100% valves). When deaerator storage tank level falls, the control valves open up to admit more water from the condensate extraction pumps. The reverse occurs when deaerator level rises.

Condenser Hotwell Level
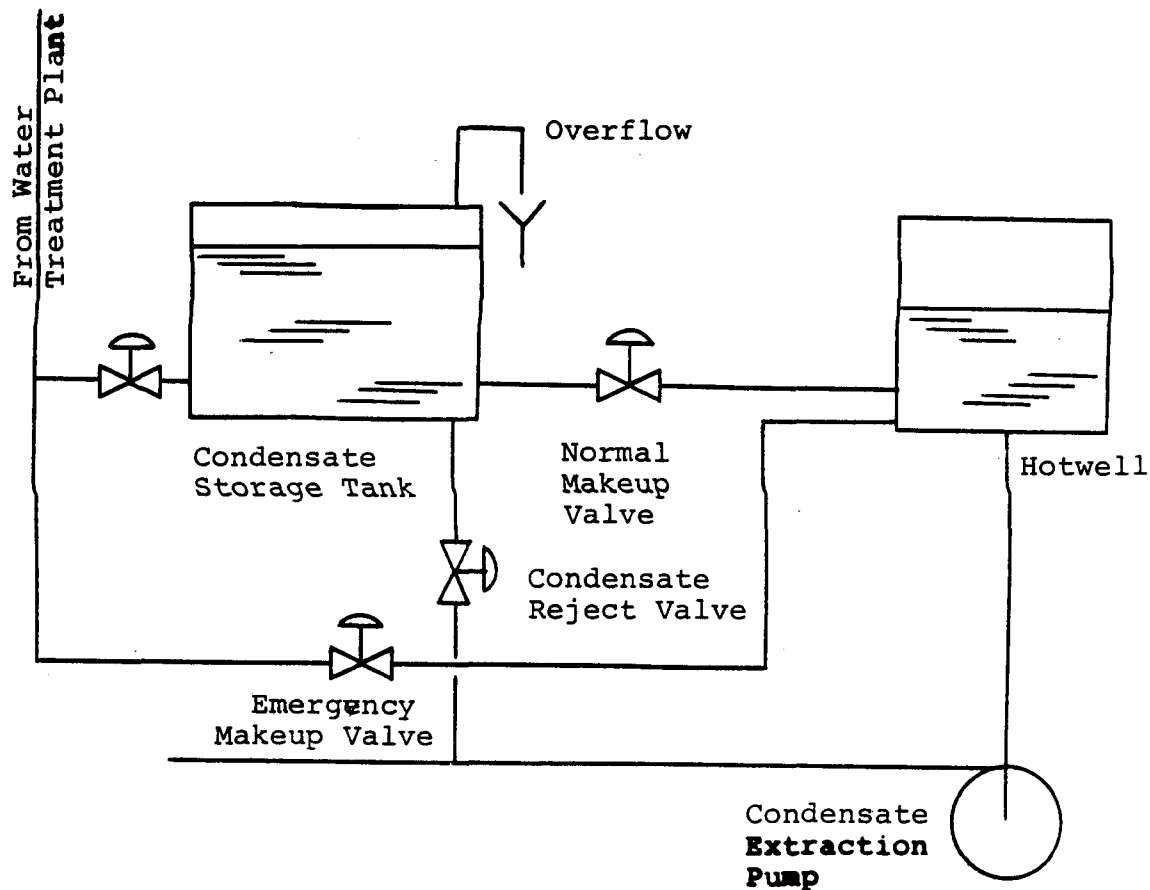
Makeup and Reject System

Figure 7.8

The level in the condenser hotwell is used to indicate the need for increasing or decreasing the inventory of water in the feedwater system. If hotwell level is too high, water is rejected from the system; if hotwell level is too low, makeup water is added to the system. Figure 7.8 shows the condensate makeup and reject system which is used to maintain hotwell level. If hotwell level drops below .5 meters, the normal makeup valve opens and water is "vacuum dragged" from the condensate storage tank into the hotwell. If the hotwell level rises above .8 meters, the condensate reject valve opens and the excess condensate is pumped back to the condensate storage tank. If the level in the condensate storage tank gets too low, water is added from the water treatment plant.

If, in an emergency, hotwell level drops below .35 meters, the large emergency makeup valve opens to admit water directly from the water treatment plant storage tanks into the hotwell.

These three level control systems (steam generator, deaerator and hotwell) work in conjunction to maintain a proper feed system water inventory. The response to a gradual increase in power would be as follows:

(a)   steam flow increases;

(b)   feedwater regulating valve opens to supply additional feedwater to match steam flow and to raise boiler level to higher programmed level;

(c)   level drops in deaerator storage tank;

(d)   deaerator level control valves open to restore storage tank level;

(e)   level begins to drop in hotwell. By this time the increased steam flow to the turbine which started the transient is beginning to enter the condenser as LP turbine exhaust. However, since the programmed boiler level increased as steam flow increased, there will be a net loss of water from the hotwell (water that was in the hotwell is now in the boiler). This will probably result in a need for some makeup water.

Since there always exists some steam and feedwater leaks and since some water is lost through blowdowns and sampling, there is a continuous loss of water from the system. Even at constant power level, the normal makeup valve will periodically open on low hotwell level to makeup for these losses.

Recirculation Lines

There is a minimum flow of condensate which must exist through the condensate extraction pumps, boiler feed pumps, air ejector condenser and gland exhaust condenser to keep them from overheating. This minimum flow is typically on the order of 10% of full power flow. Recirculation lines are fitted on the discharge of each boiler feed pump to recirculate water back to the deaerator, when the feedwater regulating valves are nearly closed. This keeps boiler feed pump flow above the minimum required. Another recirculation line is fitted downsteam of the air ejector condenser. When the deaerator level control valves are nearly closed, this recirculation valve opens. The water is recirculated back to the hotwell to maintain an adequate flow through the condensate extraction pump, gland exhaust condenser and air ejector condenser.
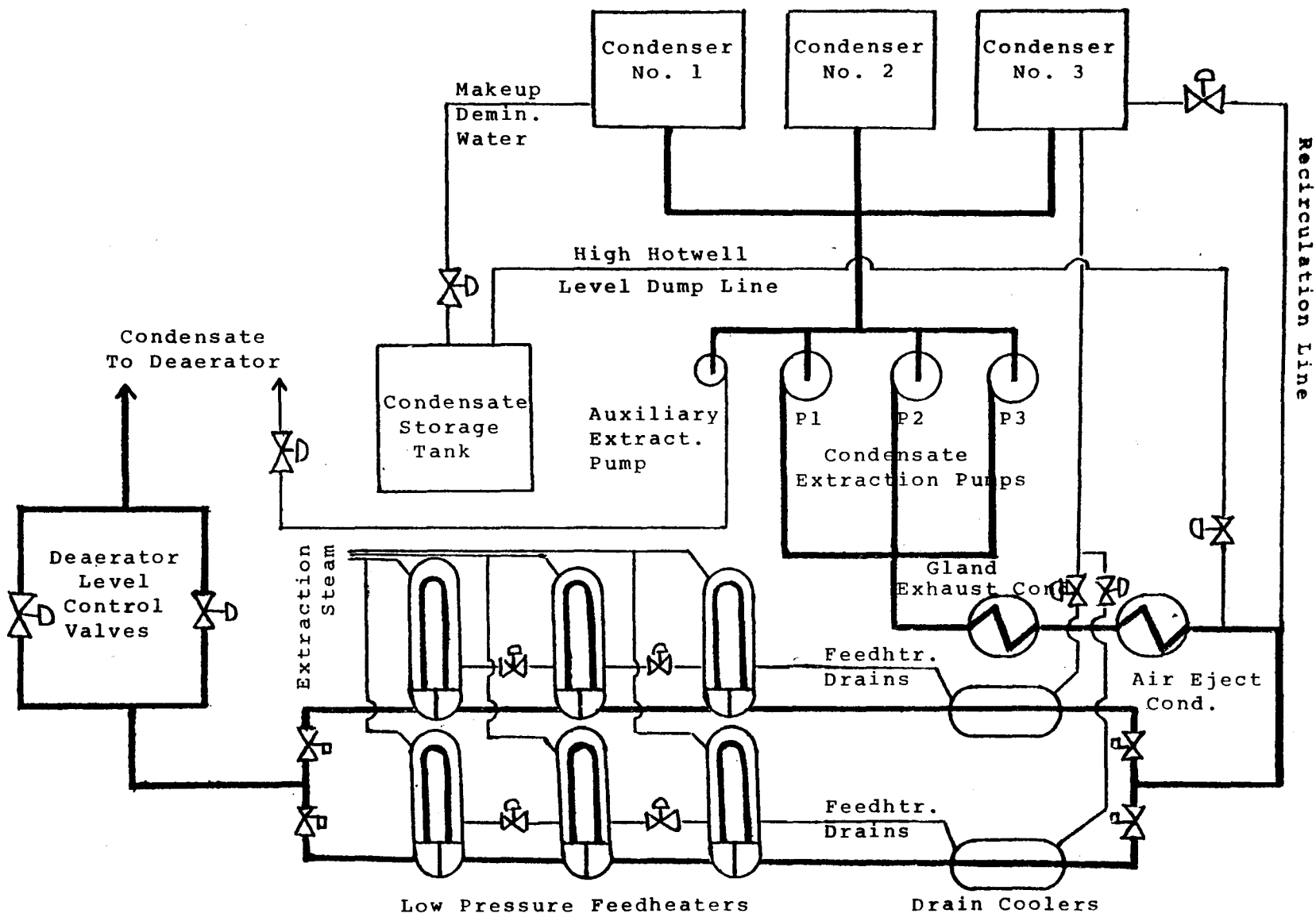
Feed System Reliability

Figures 7.9 and 7.10 show the feedwater system of a typical large CANDU generating station. Reliability is achieved by having two banks of high pressure and low pressure feedheaters. Although both banks are normally in operation, either bank is capable of handling 100% of full power flow. This allows isolation of one bank for maintenance or tube leak isolation while maintaining the plant at 100% power.

The feedwater system normally has sufficient excess pumping capacity so that one boiler feed pump and one condensate extraction pump can be shutdown and still enable 100% full power operation. The system shown in Figures 7.9 and 7.10 has three 50% extraction pumps and three 50% boiler feed pumps. Other combinations frequently encountered are two 100% pumps or two 50% and one 100% pumps.
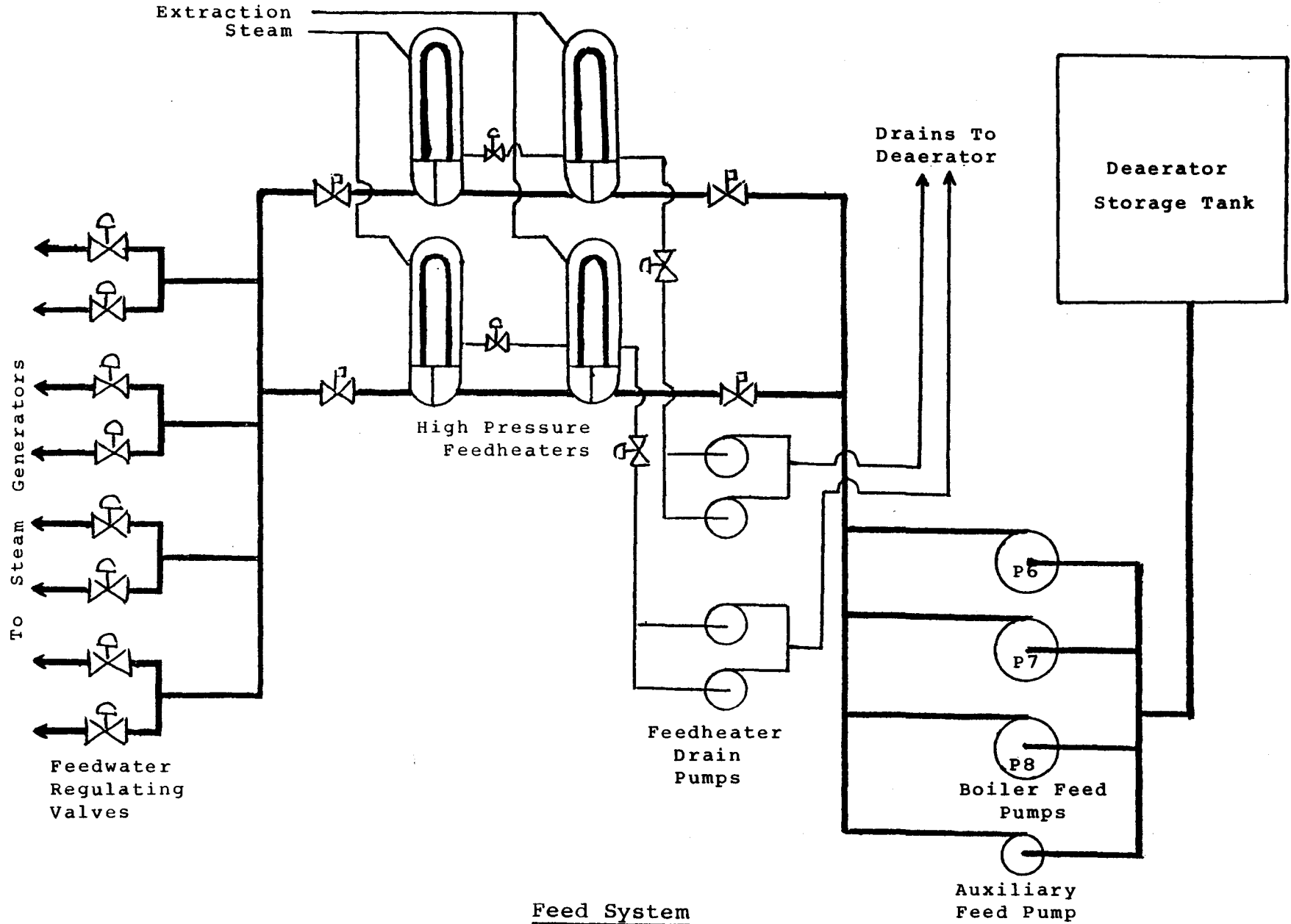
A 5% auxiliary condensate pump powered from class III power is available for maintaining deaerator level when shutdown and during reactor cooldown. A class III powered 3% auxiliary boiler feedpump is provided for use under the same conditions.

In order to recover the maximum benefit from the extraction steam to the feedheaters, the feedheater drains are cascaded. That is, the drains from one feedheater are sent to the next lower pressure feedheater. Some of the heat energy of the drain water may be recovered by allowing partial flashing of the drains back to steam in the lower pressure feedheater. In the LP feedheaters, the #3 LP feedheater drains cascade to the #2 LP feedheater, the #2 LP to the #1 LP feedheater and the #1 LP feedheater drains pass through a drain cooler and then back to the condenser.

Condenser No. 1

Condenser No. 2

Condenser No. 3

Makeup Demin. Water

Recirculation Line

High Hotwell Level Dump Line

Condensate To Deaerator

Condensate Storage Tank

Auxiliary Extract. Pump

P1 P2 P3

Condensate Extraction Pumps

Deaerator Level Control Valves

Extraction Steam

Gland Exhaust Cond.

Air Eject Cond.

Feedhtr. Drains

Feedhtr. Drains

Low Pressure Feedheaters

Drain Coolers

Condensate System

Figure 7.9

Feed System

Figure 7.10

In the HP feedheaters, #6 HP feedheater cascades to #5 HP feedheater and the drains from #5 HP feedheater are pumped back to the deaerator. This cascading of feedheater drains results in significantly more heat energy being removed from the extraction steam. If the drains were sent directly to the condenser, the sensible heat of the drains would be lost.

Feedheating Temperature Control

The flow of turbine extraction steam to the feedheaters is dependent on the differential pressure between the turbine extraction belt and the feedheater shell. Just as the pressure in the main condenser is a function of inlet lake water temperature and ccw flow, so the feedheater shell pressure is a function of inlet feedwater temperature and feedwater flow. Turbine extraction belt pressure is a function of turbine steam flow (power level). At low power virtually all of the turbine will be under a vacuum. As power increases, turbine pressure will rise, until at 100% power only the final four or five stages of the LP turbine operate below atmospheric pressure.

As power level increases, the flow of feedwater through the feedheaters increases and lowers the pressure in the feedheater shell. This increases the flow of extraction steam to the feedheater and raises the outlet temperature of the feedwater. As more extraction steam is condensed in the feedheater shell, the water level in the shell begins to rise. An automatic drain valve opens to allow more drain water to cascade to the next feedheater.

At low power levels, the low pressure in the turbine unit results in low extraction steam temperatures. This means that at low power levels the extraction steam to the deaerator and HP feedheaters is at too low a temperature to be of any value in feedheating. At low power levels, the extraction steam which would normally go to the HP feedheaters is sent directly to the condenser. Main steam is admitted to the deaerator to provide feedheating.

As turbine power increases, turbine extraction steam pressure and temperature increase. Between 25% and 50% of full power, extraction steam is automatically cut in to the HP feedheaters. In addition as extraction steam pressure to the deaerator increases, the main steam is gradually cut off, until extraction steam provides all of the feedheating.

During poison prevent operation when the turbine is shutdown or motoring there is no extraction steam available for feedheating. In this case, main steam is supplied to the deaerator to provide all of the feedheating.

Feed System Chemistry

The purpose of the various chemical treatments is to provide low conductivity, low total solids, low dissolved oxygen, and optimum alkaline conditions in our feed system and steam generators. The consequences of impurities entering the feedheating system and steam generators through condenser tube leaks is covered in considerable detail in the level 2 Chemistry course. The adverse consequences of feed-water contamination with raw lake water fall into four general categories.

1. Introduction of ionic and non-ionic impurities which may cause or accelerate localized corrosion of feed and steam generator system components particularly the steam generator tubes.

2. Introduction of impurities which can lead to formation of boiler scale on steam generator tubes which decreases the overall heat transfer coefficient of the tubes.

3. Introduction of impurities which upsets normal system chemistry which can result in increased general corrosion of components. This can be deleterious in its own right and can cause release of the oxide film from the feed system which results in an accumulation of these oxides in the steam generator.

4. Introduction of impurities which can lead to increased moisture carryover from the steam generators.

    Maintenance of feed system and boiler chemistry involves:

    (a) Minimized Dissolved Oxygen

    The presence of dissolved oxygen greatly increases the general corrosion rate of feed system and boiler materials. In addition a wide variety of localized corrosions are caused or accelerated by the presence of dissolved oxygen. Oxygen and other non-condensable gases are removed by the condenser air extraction system and the deaerator. In addition hydrazine (N_2H_4) is injected into the feed system after the deaerator. The hydrazine reacts with the oxygen and removes it.

    $$N_2H_4 + O_2 \rightarrow N_2 + H_2O$$
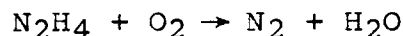
    Hydrazine decomposes fairly rapidly at boiler temperatures and must be continuously added to the feed system.

(b) **Maintain Basic PH**

Feed system and steam generator pH is maintained between 7.5 and 10.5 by addition of morpholine (diethylenimide oxide) or similar "amine" compound. A slightly basic pH minimizes the corrosion rate of feed system and boiler metals. In addition the release of metal oxides into the system is minimized. Compounds such as Na_2HPO_4 and Na_3PO_4 are gradually disappearing as methods of pH control. These compounds tend to cause long term buildup of insoluable deposits in the boiler. In addition, they contribute to boiler dissolved solids which tend to increase carryover.

(c) **Maintain Low Conductivity**

Conductivity of steam generator is an excellent measure of water purity. If conductivity increases, it is indicative of condenser leakage or poor makeup water quality. In addition high conductivity indicates high dissolved solids which may contribute to carryover. When conductivity reaches 100 μmho/cm a blowdown must be initiated, and corrective action (locate source of impurities and restore low conductivity) should be initiated as soon as possible.

There are few problems in a nuclear generating station which present the potential for long term headaches that improper care of the steam generator does. Several nuclear generating stations in the United States have experienced long shutdowns while retubing steam generators. On the other hand the short term effects of steam generator abuse are reasonably undramatic and in the early years of operation there may be a tendency to treat the steam generators as if they will go on forever.

Figure 7.11 shows the typical chemistry specifications for a large CANDU generating station.

Chemical Control Specifications

Variable	Sample Point or Indication	Sample Frequency	Range/Limit	Typical or Desired Value	Remarks
Conductivity	BOILER WATER SAMPLING STATION IN REACTOR BUILDING. EACH BOILER IS SAMPLED INDIVIDUALLY	(1) 2 boilers/shift	(6) 100 micromhos/cm	(6) 50 micromhos/cm	(1) 2 boilers per shift in each unit on rotating basis.
pH		(1) 2 boilers/shift	7.5 - 10.5	8.7	(2) Dependent on pH requirement.
SiO$_2$		once/week	(6) <10 mg/kg	<5mg/kg	(3) Tritium must be measured in all boilers if routine analysis of main steam upon resampling has shown an increase by factor of 2 or more from the previous results.
N$_2$H$_4$		(1) 2 boilers/shift	20-500 μg/kg	(2) 100 μg/kg	
Tritium		(3) (4)	(3) (4)	($\simeq$3 micro Ci/kg)	
Magnesium		(1) 2 boilers/shift	<1 mg/kg (5) (6)	<0.100 mg/kg	(4) Marked increase might indicate boiler leakage followed up by other tests, eg, gamma scan.
Sodium		(1) 2 boilers/shift	N.A. (5)	2 mg/kg	(5) High concentration may indicate condenser leakage or bad make up water.
Copper		once/week	N.A.	<100 μg/kg	(6) Boiler must be blown down immediately if its conductivity $\geq$100 micromhos but it is a good practice to blow down already at 50 micromhos. Blowdown to be also initiated if either SiO$_2$>10mg/kg, Mg>1mg/kg or Cl->10 mg/kg.
Iron		once/week	N.A.	<100 μg/kg	
Chlorides		once/week	N.A. (6)	<10 mg/kg	

Figure 7.11

ASSIGNMENT

1. Draw a schematic diagram of a typical feedheating system showing:

    (a) HP turbine extraction steam
    (b) LP turbine extraction steam
    (c) LP feedheaters
    (d) HP feedheaters
    (e) condensate extraction pump
    (f) boiler feed pump
    (g) deaerator
    (h) steam generators
    (i) feedwater regulating valves
    (j) deaerator storage tank level control valves
    (k) condensate storage tank
    (l) drain cooler
    (m) air ejector condenser
    (n) gland exhaust condenser
    (o) recirculation lines.

2. What is the function of the:

    (a) condensate recirculation line?
    (b) boiler feed pump recirculation line?

3. Explain how level is maintained in each of the following:

    (a) steam generator
    (b) deaerator
    (c) condenser hotwell.

4. Explain the sequence of events for an increase in turbine power from 10% to 100%. Include in your discussion:

    (a) steam to deaerator
    (b) steam generator level
    (c) deaerator level
    (d) hotwell level
    (e) extraction steam to HP feedheaters
    (f) condensate extraction pumps
    (g) boiler feed pumps
    (h) increase of extraction steam to feedheaters.

5. Why is makeup necessary in the feedwater system?

6. How is the reliability of the feedwater system guaranteed?

7. How and why are each of the following maintained within specifications?

    (a) pH
    (b) O_2
    (c) Conductivity.

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