26 Other Major Systems

26.1 The Generator

26.1.1 AC Generator Energy Conversion

A generator converts mechanical energy into electrical energy. The basic prerequisites to produce electricity from an AC generator are:

- there must be a conductor,
- there must be a magnetic field, and
- there must be a relative motion between the conductor and the magnetic field.

Whenever these three conditions are met, a voltage is induced in the conductor. In a practical generator, a large number of conductor coils multiply the effect.

Figure 26.1 shows a simplified arrangement of a generator coupled to a steam turbine drive. The stationary conductors (coils) and the associated iron cores are referred to as a stator. Conductors (coils) and the associated iron core, mounted on the shaft, are referred to as a rotor.

Insulated slip rings on the shaft transfer DC current to create a magnetic field in the rotor. The stator windings act as the conductors for the main generator current while the turbine provides the mechanical torque on the shaft of the generator. The rotating motion provided by the shaft produces the relative motion between the rotor magnetic field and the stator conductors. As a result, a voltage is induced in the stator conductors and transferred to the transmission lines through a step-up transformer.

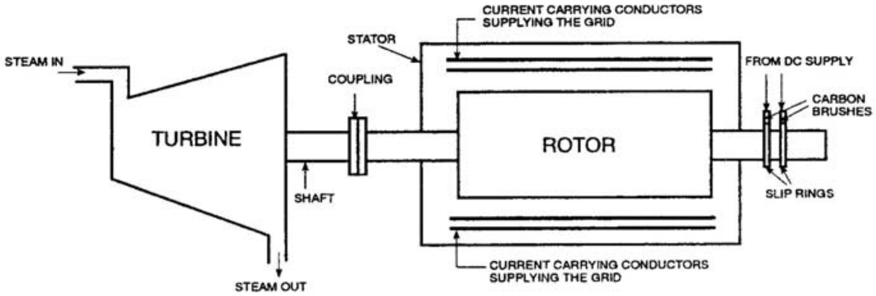


Figure 26.1
Simplified Arrangement of a Generator Coupled to a Turbine Drive

In a generator, the rotor velocity determines the frequency. When the generator is connected to the grid the frequency is fixed at 60 Hz. Since the frequency for the Ontario Grid is fixed at 60 Hz, the velocity of the rotor is kept constant. In nuclear plants this speed is generally 1800 rpm.

As electrical consumers use electricity, they create a load current on the Ontario grid, thereby increasing counter torque to the turbine shaft. The tendency of the turbine is to slow down as counter torque is increased which would decrease the frequency. To compensate for the increased counter torque more steam is admitted to the turbine to produce more shaft mechanical power and to maintain the generator speed.

26.1.2 Generator Cooling

The modern electric generator for a steam power station is an extremely efficient machine. Approximately 98% of the mechanical power delivered on the shaft from the turbine is converted to electrical power. The remaining 2% appears as heat in various places in the generator. Two percent does not appear to be very much until you consider that 2% of a 750 MW machine is equal to 15 MW. Since all of this 15 MW is converted to heat, it is like putting a heater of this size inside the generator.

The heat that is produced in a generator comes from several sources including windage (gas friction) between the rotor and the circulating cooling gas, the electrical heating due to the current resistance in the windings of both the rotor and stator, and the electrical heating due to current induced in the structural material of the rotor and stator.

Even small increases in the operating temperature of a generator will lead to rapid deterioration of the insulation on the windings. For this reason, two systems are provided to cool the generator. One system uses hydrogen circulated through the generator. Hydrogen has the advantages of:

- better thermal capacity than air,
- less damaging to insulation than air, and
- less dense than air so less heat is produced from windage.

The disadvantage is that it is explosive when mixed with air. To avoid this hazard, the generator requires very good seals to prevent air in-leakage or leakage of hydrogen out of the generator. Special procedures are required when filling and emptying the generator to prevent an explosive mixture.

By itself, the hydrogen cooling system is inadequate. To complement it, a stator cooling water system is also provided. The conductors in the stator are hollow and water is circulated through them. This water has to be exceptionally pure to prevent leakage of current from the stator conductors to ground through the coolant.

The combination of hydrogen and stator-water cooling is sufficient to cool generators as large as 1500 MW, which is far larger than any generator in service in a CANDU plant.

26.2 Electrical Systems

26.2.1 Major Components

Figure 26.2 shows a simplified diagram of a CANDU station's electrical interconnection with the power grid.

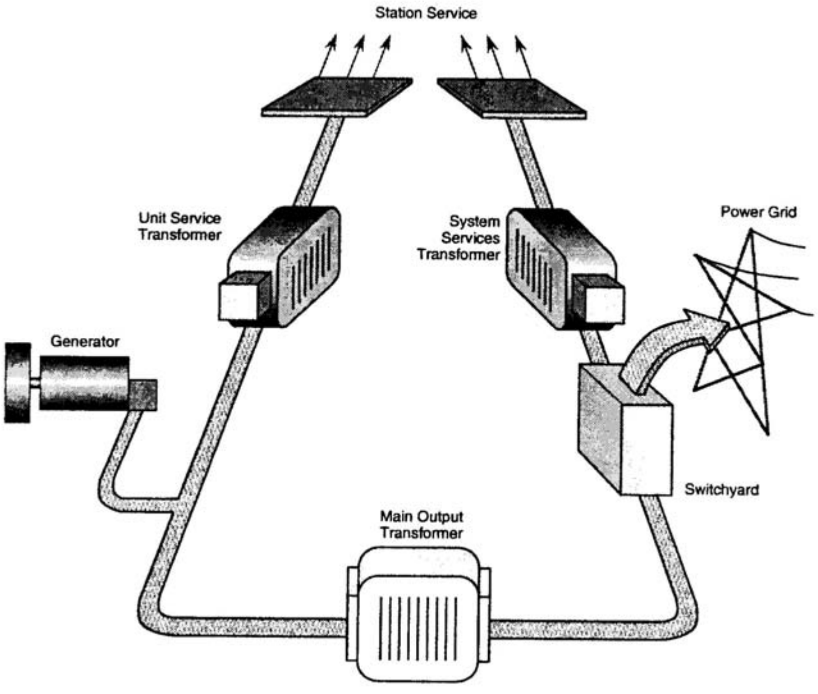


Figure 26.2
Main Power Output and Unit Distribution System

The main output transformer steps up the voltage from the unit generator to the level required by the Ontario Power Generation grid. A higher voltage means a reduced current and therefore reduced line losses over the long distances that power is transmitted.

A higher voltage means a reduced current and therefore reduced line losses over the long distances that power is transmitted.

This electrical power is delivered to the switchyard. The switchyard increases overall reliability by providing the means to switch generator output to available output lines, to isolate a faulty generator or line, and, if necessary, to draw a unit's energy requirements from the grid.

A reactor unit can draw power to meet its internal needs from two sources:

6. The unit service transformer (UST) connected directly to the unit generator. The UST is a step-down transformer that reduces generator voltage to the level appropriate for the unit.
7. The system service transformer (SST) is connected directly to the grid. This is a step-down transformer, which reduces grid voltage to the appropriate level for the unit.

The UST is the primary supply to the reactor unit and the SST is the alternate supply to the reactor unit as well as the primary supply to a portion of the common station loads.

26.2.2 Classes of Power

All power consumers (loads) in the station are not created equal. It is essential to ensure that some loads (e.g., protective relaying) never lose their power source, while others (e.g., office air conditioning) can go without power almost indefinitely. To handle the various needs, a hierarchy of four classes of power has been developed based on the urgency or importance of maintaining power to individual loads. Each class has both a normal power source and an emergency power source. The emergency power source takes over when the normal source is not available. Each class supplies power to odd and even buses. Equipment is divided up between odd and even buses to ensure independence; failure of one bus does not deprive all similar equipment of power. In the case of redundant equipment, for instance two 100% pumps, one piece would be supplied from an even bus and the other from an odd bus. Figure 26.3 graphically illustrates the four classes of power, the alternate sources for each and the odd/even arrangement.

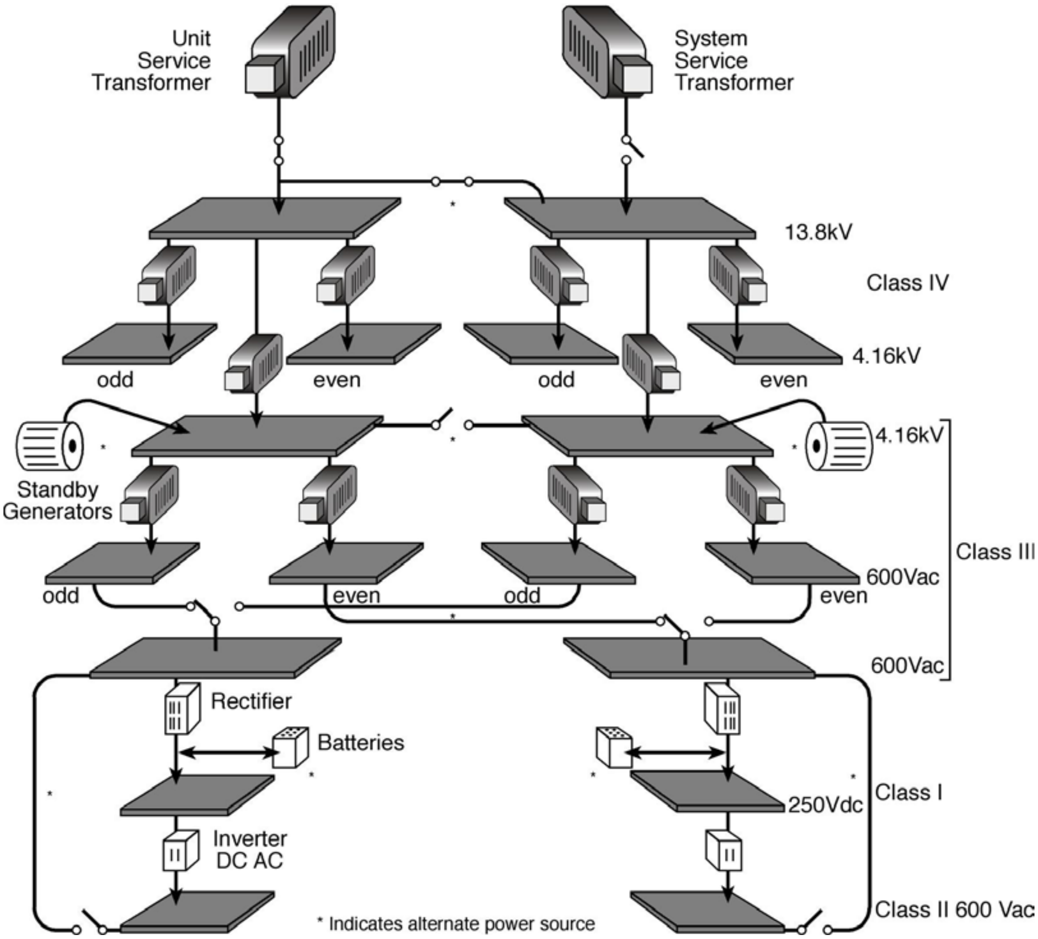


Figure 26.3
Classes of Power and Distribution

Class IV Power
Class IV power supplies AC loads that can be interrupted indefinitely without affecting personnel or plant safety. Typical loads on a Class IV system are normal lighting and the primary heat transport pump motors. During normal operation, the UST carries the reactor unit loads. Should the need arise; the loads can be supplied fully by the SST. Thus, the electrical grid system serves as an emergency power supply for the Class IV system.

Class III Power
Class III power supplies AC loads that can tolerate the short interruption (one to three minutes) required to start the standby generators without affecting personnel or plant safety, but are required for safe plant shutdown. Typical loads on a Class III system are the moderator main circulation pump motors and the pressurizing feed pump motors. Normally, Class III power is supplied from a Class IV

source. Should a supply path from the UST and the SST both fail, then one or more of the standby generators (gas turbine driven) will automatically start and begin picking up the loads. This process is initiated in approximately three minutes.

Class II Power

Class II power is considered uninterruptible. Class II supplies AC loads that cannot tolerate the short interruptions, which can occur in Class III. Typical loads on a Class II system are digital control computers and reactor safety systems. Class II power is normally fed from Class I via an inverter which changes DC to AC. Should the Class I supply fail, Class II power can be supplied from Class III while high priority action is taken to restore the Class I supply. In this situation, it is normal to start a standby generator and hook it to Class III.

Class I Power

Class I power is considered uninterruptible. Class I supplies DC loads that cannot tolerate the short interruptions which can occur in Class III. Typical loads on a Class I system are protective relaying, circuit breaker control, turbine lube oil emergency pump, emergency seal oil pump, and emergency stator conductor water cooling system pump. Class I is normally obtained from Class III, via a rectifier (battery charger). Should the rectifier or the Class III supply fail, then Class I is supplied from a battery bank, which is normally maintained fully charged by the rectifier.

26.2.3 Emergency Power Supply (EPS)

In the unlikely event of a loss of all Class IV and III power the emergency power supply (EPS) provides electrical power to certain nuclear safety-related systems that support the capability to control, cool, and contain. The EPS is started automatically on the loss of power to certain 600V buses on the common unit or it can be manually started from the EPS control room within 30 minutes of an identified need. It is seismically and environmentally qualified and has sufficient fuel stores to operate unaided for a seven-day period. Seismic Qualification requires that equipment and systems retain their specified performance capability following an earthquake. Environmental Qualification (EQ) requires that equipment must be protected against steam leaks, water flooding, high intensity fires or other mishaps, which could disable it. The EPS must be available whenever there is a significant amount of fission products in a reactor core. The EPS system in older stations may not be named the same or be as extensive as in new stations.

Some worst-case accidents, which could lead to a need for an emergency power supply, are:

- tornado,
- widespread fires, and
- earthquake.

The EPS is quite similar to other standby generators but is remotely located from the standby generators to reduce chances of it being disabled by the same incident. Cables and control equipment involved in switching the Emergency Power Supply into service are routed through areas that are considered to be at lowest risk of damage

26.3 Water and Air Systems

26.3.1 Light Water Systems

Water for all purposes (cooling, feedwater make-up, fire protection, domestic use, etc.) is drawn into the nuclear station's intake channel from the lake through a tunnel, which extends approximately 600 meters out under the lakebed. Each unit has its own pump-house to supply condenser cooling water and service water. Domestic water and demineralized water for feedwater make-up are supplied from a water treatment plant to all units in a station station. System interconnections are shown in Figure 26.4. The systems shown (except water treatment) are duplicated in each unit.

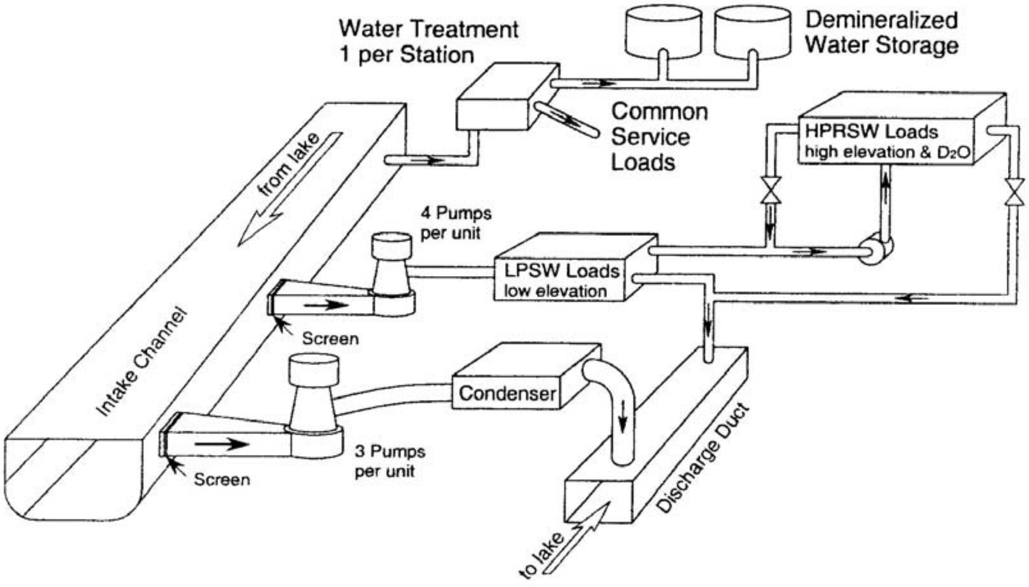


Figure 26.4
Water Systems

26.3.2 Water Treatment

Water treatment has two purposes:

- to remove harmful constituents from the water, and
- to treat the water with beneficial ingredients.

The water treatment plant produces demineralized water primarily for boiler feedwater makeup, but also for end-shield cooling, the closed loop demineralized water-cooling system, the irradiated fuel bay, and the chemistry lab. The chemical treatment process for each water system is varied. Demineralized water is essential in systems that must be protected from corrosion or the build-up of scale and crud.

26.3.3 Condenser Cooling Water

The purpose of the Condenser Cooling Water (CCW) system is to supply strained lake water to the condensers. The only treatment this water receives is filtering through screens to remove small debris such as entrained organic matter.

The CCW is one system required to have a certificate of approval. The CCW system must be capable of removing 70 per cent of the reactor's thermal power, but the certificate of approval requires it to do this without raising the discharge temperature more than 11°C above lake water temperature. To meet this requirement, the system must provide flows in the range of 31 m^3/s for each unit. Over 85% of a station's total cooling water flow is required for condenser cooling. About four MW of electricity is required to drive the pumps for each unit.

26.3.4 Common Service Water

The Common Service Water system (CSW) provides a continuous flow of water to the Central Service Area, the Water Treatment Plant, the Vacuum Building, and the Ancillary (Auxiliary) Services Building. Common service water is strained and filtered before being distributed. It provides water for cooling, waste dilution, lawn watering, etc.

26.3.5 Low-pressure Service Water

The Low-pressure Service Water system (LPSW) provides a continuous flow of strained lake water for specific cooling purposes such as to seals, bearings, and heat exchangers. The temperature of the LPSW ranges from 2°C to 27°C. The LPSW draws its supply from the intake channel.

26.3.6 High-pressure Recirculating Service Water

The High-pressure Recirculating Service Water System (HPRSW) is fed from the LPSW system. It increases the pressure and tempers the water to 15°C to 30ºC by directing some of its outlet flow back to its inlet. It serves all applications where potential D_2O freezing is a problem or where equipment is located at high elevations within the plant. D_2O has a freezing point of about 4ºC, 4 degrees warmer than a typical lake in Canada in January. Typical loads are the closed loop demineralized water cooling system heat exchangers, Moderator pump motors, H.T. feed pump oil coolers, maintenance cooling pumps, D_2O vapour recovery dryers, and heat transport pumps.

26.3.7 Closed Loop Demineralized Service Water System

The Closed Loop Demineralized Service Water system is used to provide cooling to plant equipment where the impact of corrosion is of particular concern. Typical loads are the H.T. bleed cooler and gland seal cooler, the delayed neutron water boxes, and the H.T. Pump neutron shields.

26.3.8 Emergency Water System

The Emergency Water system (EWS) is environmentally and seismically qualified. It provides cooling water to critical systems when the normal systems (boiler feedwater and LPSW, and/or Class IV and III power) are unavailable. It draws its power from the EPS. Emergency water can be routed to the boilers, to the ECI heat exchangers, the H.T. System, the vault coolers or the primary and secondary irradiated fuel bay heat exchangers as required. The EWS draws its water from the station outfall, providing an independent source in the event that the supply from the forebay is not available.

26.3.9 Other Water Systems

The Fire Protection Water system provides water for fire fighting to areas such as fire hose cabinets in the station, hydrants, transformer deluge systems, turbine sprinkler systems, and an air foam system. In emergencies, it can supply water to the irradiated fuel bay, the ECI system, the vacuum building emergency water storage tank and the moderator heat exchangers. The system draws its supply from the common service water intake duct.

The Domestic Water Distribution system is different at each station but its uses are common. Hot and cold potable water is supplied to the plumbing fixtures (toilets, urinals, sinks, showers, drinking fountains, eyewash stations, safety showers) and laundry machines as required in the station, and ancillary buildings. Supply is drawn from a local pump house or the water treatment plant.

26.4 Air systems

A CANDU station has numerous uses for compressed air. The quality of the air required depends on the application. To handle the varying requirements, the station has a number of different compressed air systems.

26.4.1 Instrument Air

The Instrument Air system provides instrument quality compressed air to all parts of the station. There are actually a number of systems, one for the common areas of the station, and one each for the units. This air is used for control valve actuators, power operators, pneumatic controllers, and special applications in the chemistry lab and irradiated fuel bay where service air is of insufficient quality.

26.4.2 Service Air

The Service Air system provides general purpose compressed air to all parts of the station. This air is used for air-powered tools, cleaning, and water treatment plant regeneration.

26.4.3 Breathing Air

The Breathing Air system supplies breathing air to any areas of the plant in which personnel may require plastic suits. The primary use is for personnel working inside the reactor vault during shutdowns. Most of the air supplied to the plastic suits is for cooling.

26.5 Identification System

26.5.1 Equipment Identification

A standardized numbering system has been adopted as system of identification. This is supplemented in the field by colour coding and tagging, and on drawings (flowsheets) by equipment symbols. Although in principle the numbering system is identical in each stations, it does vary in detail. This system specifies all of the equipment and most operations in the station.

The system is subdivided into divisions. Figure 26.5 shows how some of these divisions relate to station systems.

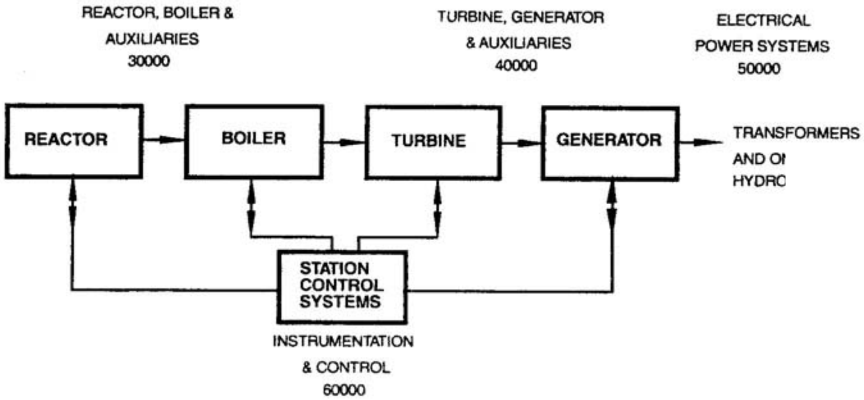


Figure 26.5 Equipment Numbering Divisions

The complete set of Divisions are:

Division 0	General Project
Division 1	Site and Improvements
Division 2	Buildings, Structures and Shielding
Division 3	Reactor, Boiler and Auxiliaries
Division 4	Turbine, Generator and Auxiliaries
Division 5	Electric Power Systems
Division 6	Instrumentation and Control
Division 7	Common Processes and Services
Division 8	Construction Indirects

Each division is further subdivided as shown below. A five-digit number allows the specification of an individual component of any system in a plant. An example from Division 4 illustrates the structure of the system.

It should be noted that below the system level, the numbering system may be changed to suit particular station needs.

Division	**4**0000	Turbine, Generator and Auxiliaries
Major System	4**2**000	Condensing System
System	42**1**00	Main Condensing System
Sub-System	421**2**0	Condenser Extraction System
Components	4212**1**	Ejectors
	4212**2**	Vacuum Pumps
	4212**3**	Valves
	4212**8**	Pipe Supports
	4212**9**	Piping

26.5.2 Field Identification

In the field, the system number and a brief written description are found either printed on the equipment or on a tag attached to the equipment. Where more than one component of the same kind (e.g., valves) is contained within a sub-system, a special device code is provided in place of the component digit in the system. This code consists of a descriptive letter (P for pump, V for valve, etc) and a unique number. For example, 42123 which indicate any valve in the condenser air extraction system could be changed to 42120-V2 or 42120-V15 to indicate a specific valve in the system.

26.5.3 Piping

For quick identification, piping is colour coded to indicate the type of fluid it contains. Also, an arrow is attached showing the direction of flow. Colours commonly used are:

Air	Blue
Heavy Water	Pink
Light Water	Green
Steam	Silver (Aluminium)
Oil	Yellow
Gases	Brown
Building Heating	White
Drains & Sewage	Black
Fire Protection	Red
Vacuum	Purple
Chemicals	Orange

26.5.4 Flowsheets

Each station maintains a complete set of system drawings called flowsheets. The flowsheets are graphical representations of the systems using standard symbols to represent equipment and devices. The flowsheets are labelled using the number system and the equipment and device code labels on the flowsheets are identical to the codes used in the field. Interrelationships between systems are indicated by reference to other flowsheet numbers. Complete sets of flowsheets and the legend of symbols are maintained by the records section of the station.

26.6 Waste Management

26.6.1 Liquid Waste Management

Like any large facility, a CANDU station has an extensive network of floor drains to collect spills and drainage from its various processes. Because of the nature of the business, it is necessary to subdivide the drainage system into:

- inactive drainage, and
- active drainage.

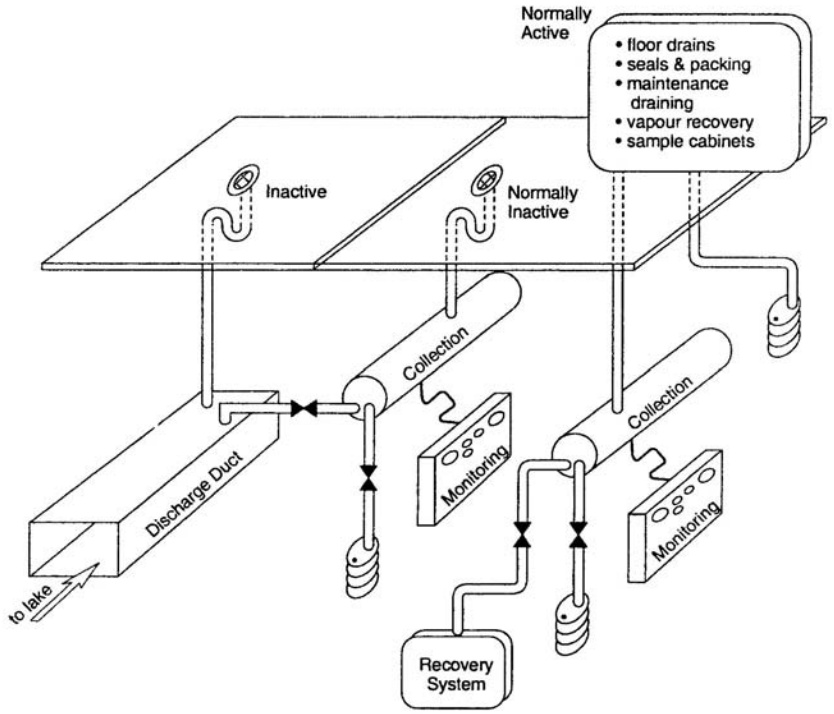


Figure 26.6
Drainage System

26.6.2 Inactive Drainage

The inactive drainage system collects drainage from the conventional side of the station. The waste discharges to the condenser cooling water discharge channel or intake channel depending on the location. Clean drains such as leakage collection from the main steam blowdown pipe trenches are returned to the lake through yard drains. The resin regenerant waste effluent from the water treatment plant is monitored for pH and discharged under controlled conditions to the condenser cooling water discharge channel.

26.6.3 Active Drainage

The active drainage system collects drainage from the reactor side of the station. Because the volume of water from these areas is quite large, the system further segregates the drainage into normally inactive drainage and normally active drainage to minimize the amount of water requiring treatment prior to disposal.

Normally Inactive Drainage

This drainage contains very little or no activity, but it is collected prior to discharge to ensure that it can be treated if contamination occurs. The major sources are reactor building floor drains, laundry drains, and non-active laboratory sinks and floor drains.

Normally Active Drainage

This drainage is expected to have activity so it is collected and sampled to determine the required treatment prior to release. The major sources of normally active waste are the reactor auxiliary bay floor drains, irradiated fuel bay drainage, spent ion exchange resin slurry water, auxiliary irradiated fuel bay drainage, active chemical laboratory drains, decontamination centre drains, fuelling machine maintenance shop drains, laundry first rinse cycle drains, and decontamination shower drains.

Reactor building drains are diverted to the reactor building liquid recovery system to recover heavy water.

26.7 Solid Waste Management

26.7.1 Irradiated Fuel Storage

Stations do not produce large amounts of high-level radioactive material. A four unit 850 MW station produces an average 20,000 irradiated fuel bundles per year (390 Mg per year).

Irradiated fuel is stored in pools of demineralized light water called Irradiated Fuel Bays (IFB). The water provides cooling, shielding for personnel, and visibility, and it also allows easy handling without removal. In the short to medium term, the IFBs at each station are more than adequate to handle the irradiated fuel, but in time, there may be a need to move the older fuel into dry storage on site. This is feasible because over time, the radiation levels and heat produced by the fuel drops off significantly. Several sites now have some of the fuel used at the site stored in dry storage containers at the site.

26.7.2 Waste Volume Reduction and Storage

A typical radioactive waste storage facility is designed to reduce, by incineration or compacting, the volume of waste that requires storage. These facilities handle both low and medium level radioactive waste.

Radioactive waste is trucked to the facility in specially designed metal containers. If possible, the waste is incinerated and the radioactive ash loaded into 200 litre drums with a volume reduction about 20 to 1. Waste that cannot be burnt because of metal content or high radioactivity is compacted with a volume reduction about 4 to 1.

After treatment, the radioactive waste is reclassified as low, medium or high level. Low-level waste is stored in a warehouse. Medium level waste is stored in deep trenches. High-level waste is stored in deep tile holes.

Examples of radioactive wastes are:

- rags and protective clothing (low, medium or high level),
- equipment components or tools (medium or high level),
- H.T. gland seal filters (high level),
- Moderator & H.T. spent ion exchange resin (high level), and neutron activated components from the reactor core (high level).

26.8 Heavy Water Management

Heavy water is very expensive to produce and when it is used in a reactor it becomes radioactive largely due to the production of tritium. It is therefore critical that heavy water is managed in such a way as to:

- minimize permanent losses,
- reduce our environmental emissions, and
- minimize the chronic hazard to personnel.

Figure 26.7 shows the systems used for managing D_2O in a CANDU station.

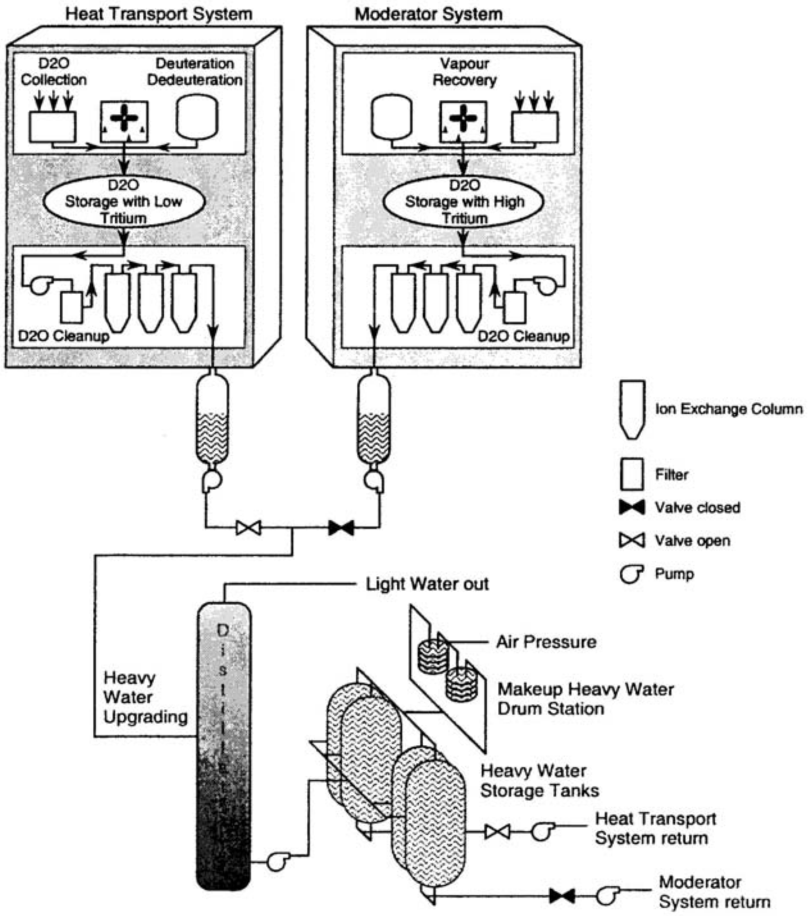


Figure 26.7
CANDU Station D_2O Management Systems

26.8.1 Loss Recovery

Part of the cost of operating a CANDU station is the D_2O upkeep cost. This consists both of replacement costs for D_2O lost permanently to the station, and the cost of upgrading D_2O that has been downgraded (isotopic below limit).

D_2O can be lost permanently through:

- vapour losses (the largest factor),
- discharge of wet fuel bundles to the irradiated fuel bay,
- resin deuteration and dedeuteration which produces some downgraded D_2O that is not recoverable,
- D_2O sampling and analysis,
- component decontamination,
- the top product from the upgrader which contains a small percentage of unrecoverable D_2O, and
- moderator heat exchanger leaks.

To minimize D_2O losses, vapour recovery and special collection systems are employed. The areas where vapour losses are most likely have closed loop ventilation systems containing vapour recovery driers, which reclaim most of the vapour. The recovered D_2O is always downgraded due to mixing with moisture in the air. Despite this recovery system, vapour loss makes up the largest fraction of permanent heavy water loss.

Deuteration is a process of exchanging the light water ions on IX column resins with heavy water ions to ensure no downgrading when the columns are placed in service. The resin must be dedeuterated prior to disposal to recover the heavy water.

There are two types of D_2O liquid collection system. The open method uses drip trays under potential leak points such as flanged joints (used rarely). The closed system conveys leakage directly to collection tanks without it coming in contact with the atmosphere to prevent downgrading from moisture in the air. This type of leakage generally occurs from double-packed valve stems or bellows-sealed valves.

26.8.2 Upgrading

If D_2O is downgraded below a certain isotopic then it is not worth recovering. If it is economical to recover the D_2O then it is passed through a station upgrader. The upgrader uses distillation to separate the heavy water from the light water. The output is 99.9% or greater D_2O.

26.8.3 Tritium Removal

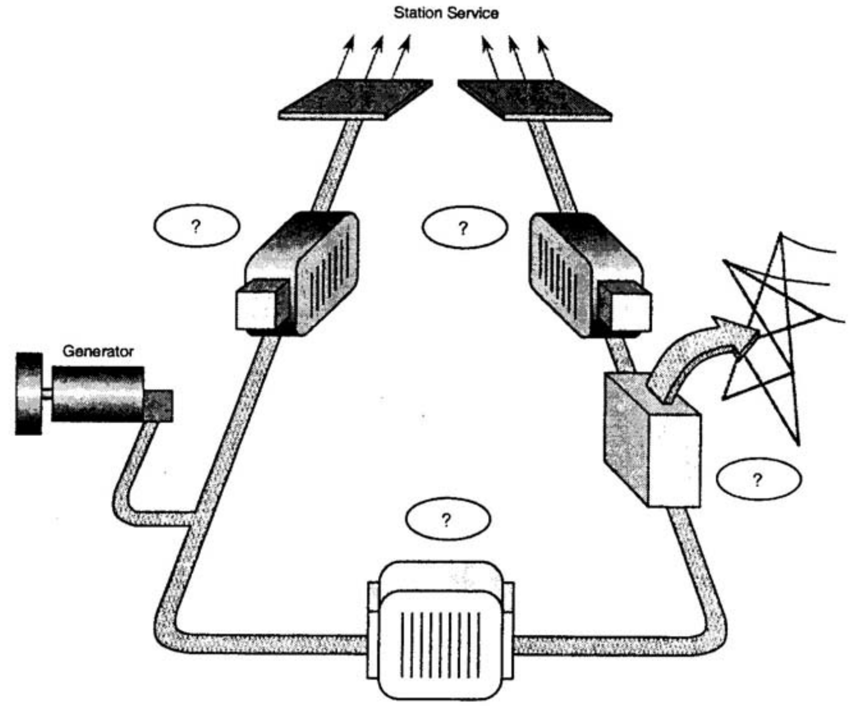
The Tritium Removal Facility (TRF) located at Darlington NGS forms a part of the heavy water management system. The TRF has the capability to remove tritium in batches of moderator and heat transport system D_2O. Replacing water in the Moderator and H.T. systems with this low tritium level water effectively dilutes the tritium levels in these systems and thereby reduces the tritium hazard to personnel. The extracted tritium is marketed commercially.

26.9 Assignment

1) What are the three basic prerequisites to producing electricity in an AC generator?

2) How is heat produced in an AC generator and what two methods are used for removing it?

3) In the basic CANDU power system diagram shown below, label and briefly explain the purpose of each component identified by a question mark (?).



4) Fill in the following table.

Class of Power	Length of Possible Interruption	Normal Power Source	Alternate Power Source	Example
Class IV				
Class III				
Class II				
Class I				

5) What is the purpose of the EPS?

6) State the purpose of the following systems:

a) Water Treatment Condenser
b) Cooling Water Common Service Water
c) Low-pressure Service Water
d) High-pressure Recirculating Service Water
e) Closed Loop Demineralized
f) Service Water System

5) What is the Emergency Water System and from where does it draw its supply?

6) State the purpose of the following systems:
   a. Instrument Air
   b. Service Air
   c. Breathing Air

7) Why is irradiated fuel stored in deep pools of water?

8) Why is it important to reduce the volume of solid wastes

9) Why is D_2O managed so carefully?

10) Where might losses of D_2O occur and what systems are in place to keep these D_2O losses to a minimum?

11) What function is served by the Tritium Removal Facility?