

Reactor, Boiler, & Auxiliaries - Course 233

CONTAINMENT SYSTEM

I. INTRODUCTION TO CONTAINMENT

The containment system is provided specifically to cater for a rupture of the HT system high pressure boundary, and is designed to be able to contain essentially all energy (in the form of overpressure and heat) and radioactivity released during the maximum credible piping rupture of a loss of coolant accident (LOCA).

The system is basically an envelope which contains within it the high pressure piping components of the HT and HT auxiliary systems. It is rupture of these components which could lead to a large release of HT D₂O and activity.

Tritium activity will of course be released inside containment on a LOCA with some fission product activity from the soluble fission products (mainly iodine) always present in small concentrations in the HT D₂O. Large amounts of fission product activity will not be released on a LOCA unless the ECCS system fails to provide adequate cooling to match the heat production from decay heat, in which case, fuel failure is likely. If fuel failures occur, then substantial quantities of fission products (mainly gases and vapours) will be released inside containment.

The criteria for determining the containment envelope effectiveness is the time integrated leak rate during and after a large loss of coolant accident. This simply means there are limits set on the leak rate out of containment during an accident situation. The containment is the last physical boundary available to prevent the escape of activity to the environment if the other barriers have failed (fuel pellet, fuel sheath, heat transport piping).

The basic principles associated with the containment system, which is applied by the operator at all times to try to ensure that leak rate limits are met, is to minimize the leak rate out of containment that may be occurring from any possible source of leaks.

Depending upon the station the containment system may actually form an envelope around more components than just the high pressure HT piping. Older stations in particular tend to have larger containments than newer stations.

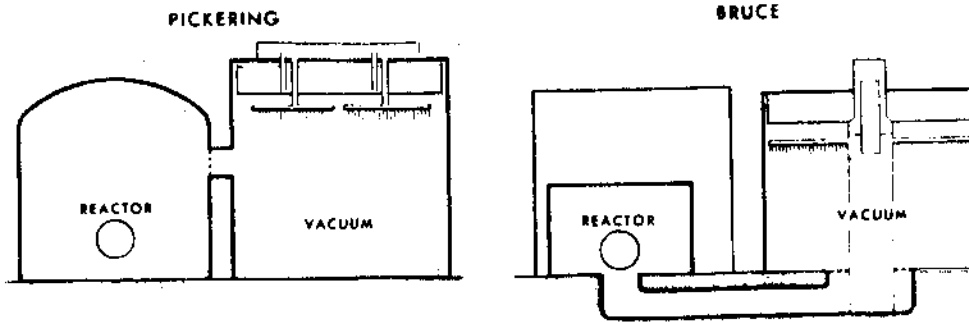


Figure 1: Relative Sizes of PNGS/BNGS Containment

Figure 1 shows the smaller size of the Bruce NGS-A containment relative to Pickering NGS-A containment to illustrate this. The reason for smaller containment envelopes is that newer stations have more equipment located outside containment. In particular at Bruce primary heat transport pumps and steam generators are located mainly outside of, but penetrating, containment. Figure 6 shows an example of a Bruce NGS-B steam generator containment penetration seal. In addition, at Bruce, there are no areas normally accessible on power within containment. At Pickering, however there are various shielded areas within containment which can be entered during reactor operation. This feature is one of the reasons Pickering has a larger containment volume than Bruce.

II. TYPES OF CONTAINMENT SYSTEMS

Two major types of containment are used on large CANDU reactors:

- (a) Pressure Suppression System
- (b) Vacuum Containment System

The first type is used on large single-unit plants, eg, Douglas Point and the Candu 600 MW(e). The second type is used on the multi-unit plants, eg, Pickering NGS, Bruce NGS, and Darlington NGS.

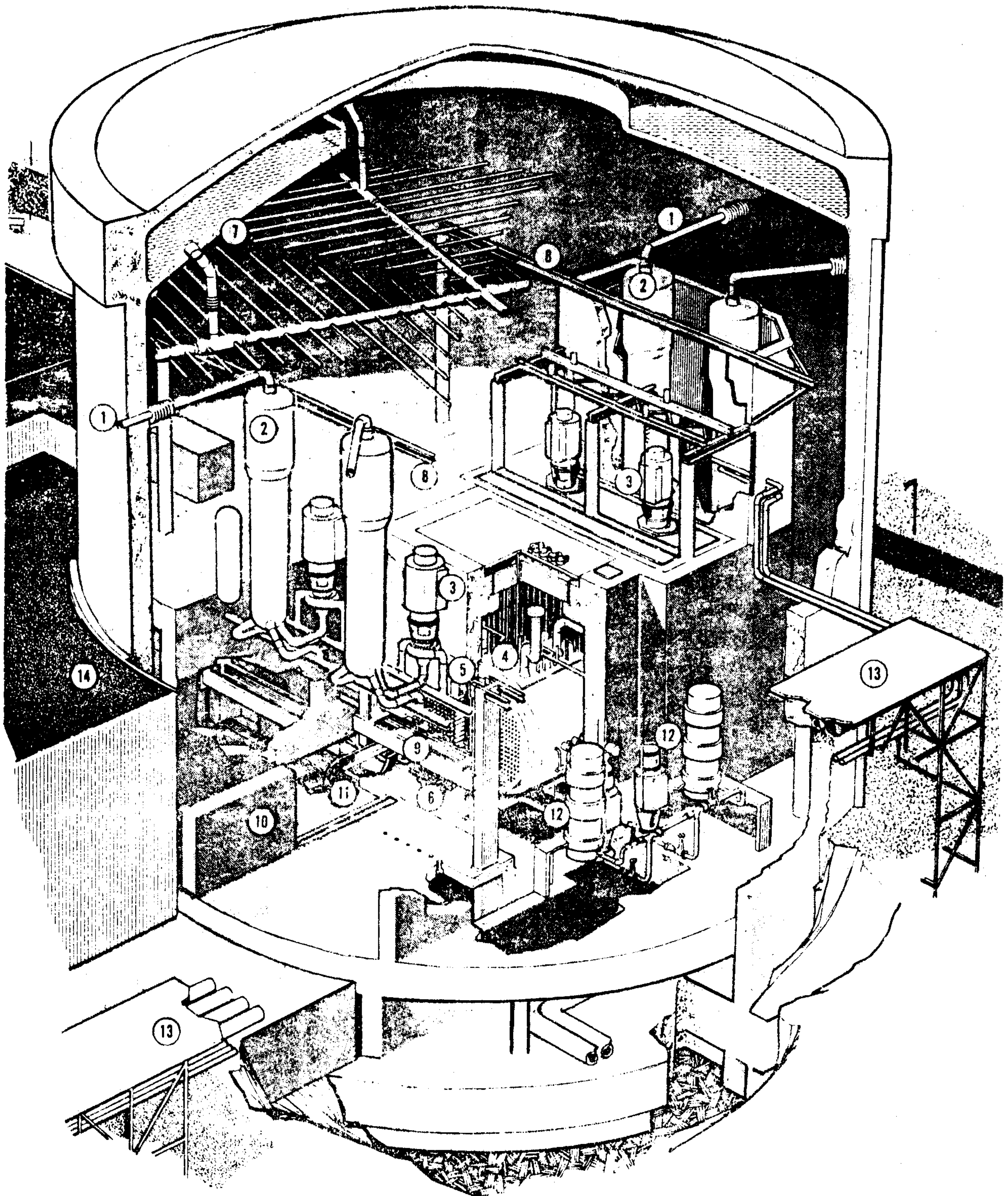
(a) Pressure Suppression System

Pressure Suppression containment is illustrated for the Candu 600 MW(e) system in Figure 2. The reactor building, have thick (1-2 m) concrete walls and a thick steel dome, is designed to withstand an internal pressure of 124 kPa(g) and to leak not more than 0.5% of total volume/day. The Douglas Point specifications are less severe due to the smaller reactor size). The walls and dome in this system are the containment 'envelope' around the HT systems.

To suppress the pressure surge following a LOCA, light water spray dousing inside containment is used from a large water storage facility built into the reactor building as shown.

Dousing provides a number of functions during a LOCA:

- (1) It absorbs heat energy from the lost coolant thereby suppressing the pressure rise inside containment.
- (2) It also reduces the time period of the overpressure excursion within containment compared to the time for overpressure if no dousing were used.
- (3) The dousing water will entrain insoluble fission products released into the vacuum building, and help to prevent contamination spread by retaining these fission products on the vacuum building floor. Soluble fission products such as I-131 will be dissolved to a certain extent in the dousing water, but noble gases such as Krypton and Xenon will be unaffected by dousing, and very prone to atmospheric release in the event of a containment leak.



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|---|---------------------------|----|------------------------------|
| 1 | MAIN STEAM SUPPLY PIPING | 9 | FUELLING MACHINE |
| 2 | BOILERS | 10 | FUELLING MACHINE DOOR |
| 3 | MAIN PRIMARY SYSTEM PUMPS | 11 | CATENARY |
| 4 | CALANDRIA ASSEMBLY | 12 | MODERATOR CIRCULATION SYSTEM |
| 5 | FEEDERS | 13 | PIPE BRIDGE |
| 6 | FUEL CHANNEL ASSEMBLY | 14 | SERVICE BUILDING |
| 7 | DOUSING WATER SUPPLY | | |
| 8 | CRANE RAILS | | |

Figure 2: Reactor Building Cutaway (Pressure Suppression Containment System)

The capital cost of containment at the present time, favours independent containment for up to two unit stations. Three or more units are required before the multi-unit "vacuum" containment (below) can be justified economically. All the presently committed plants using 600 MW(e) units employ only one of two such units with independent pressure suppression containment.

(b) Vacuum Containment System

This system a unique Canadian design, sometimes called a negative pressure containment system, is a feature of our multi-unit Candu Stations. The principle involved in negative pressure containment is that within minutes after any accident resulting in overpressure in a reactor building, the pressure within the containment boundary would be below that of the surrounding atmosphere. Hence, after the initial overpressure transient, no outward leakage would take place. The complete system consists of the reactor buildings, the vacuum building, the pressure relief system, the vacuum system and the dousing system. (See Figure 3 and 4.)

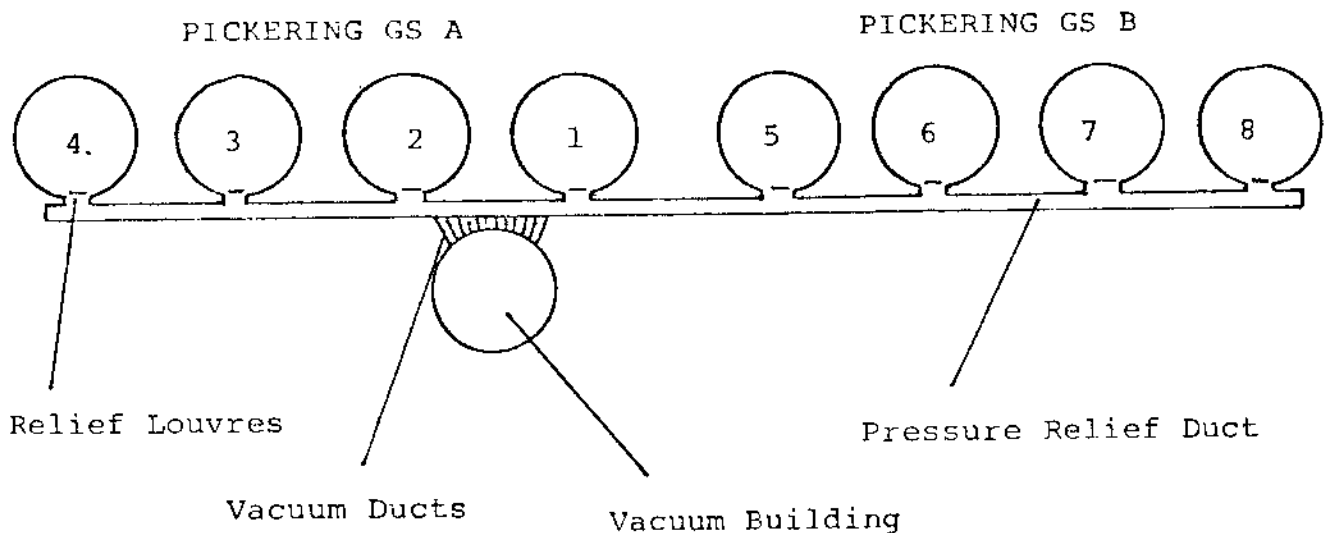


Figure 3: Major Components of Vacuum Containment System at Pickering NGS

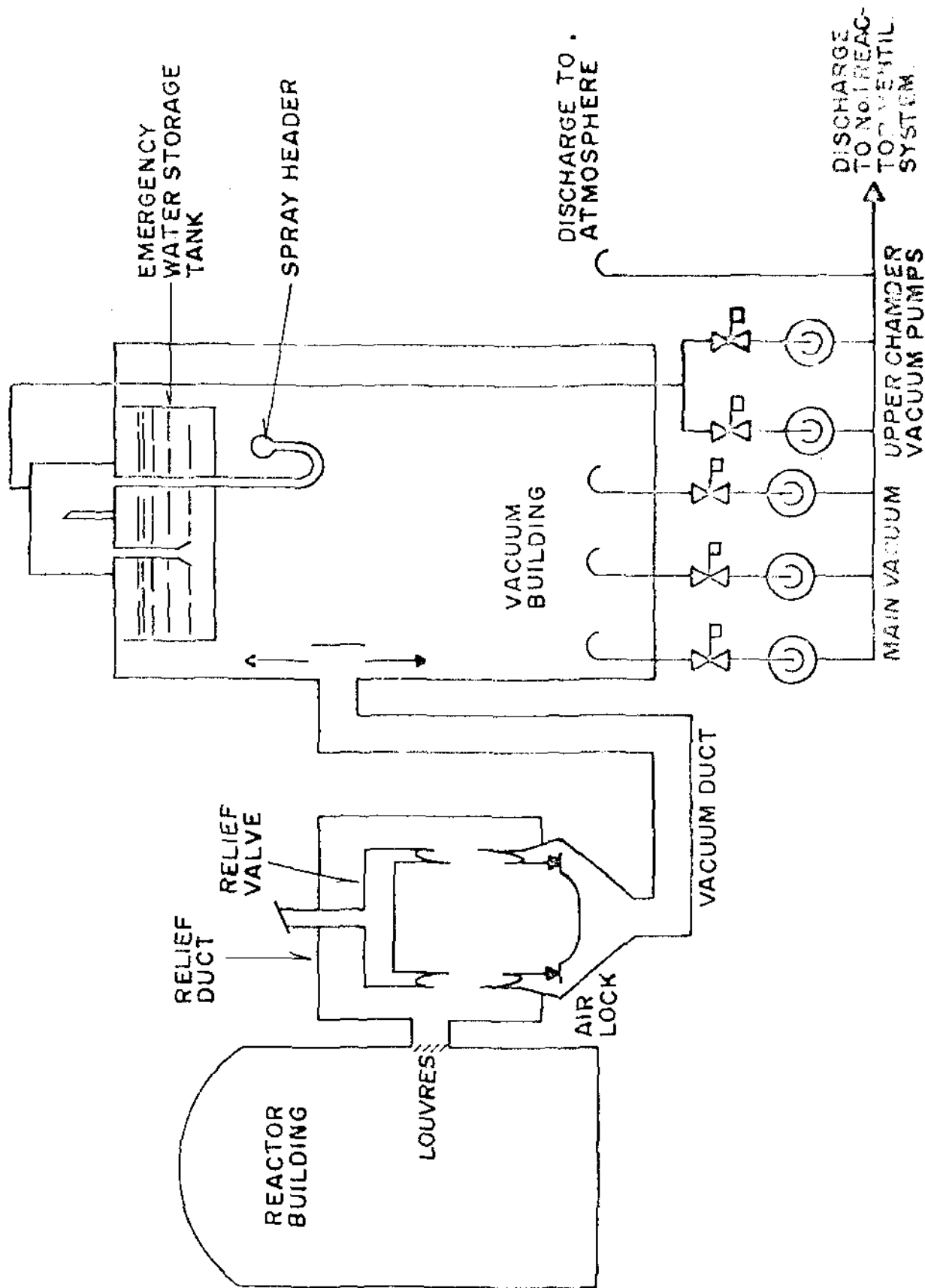


Figure 4: Vacuum Containment (Pickering NGS)

The reactor buildings at Pickering and Bruce use conventionally reinforced containment structures, cylindrical at Pickering NGS and rectangular at Bruce NGS (to scale in Figure 1). The PNGS reactor buildings are connected via a pressure relief duct to the large cylindrical vacuum building, see Figure 3. The Bruce NGS buildings are joined by means of an underground fuelling machine duct, which itself is joined by an underground duct to the vacuum building. In both stations, the vacuum building is isolated from the reactor building and relief duct by pressure relief valves.

The containment volume at Bruce is smaller than at Pickering, as mentioned earlier, because the steam generators and some other equipment eg, primary pump motors are located outside containment at Bruce unlike Pickering. This means that less air is carried with any escaping steam into the vacuum building, so that the vacuum building can also be smaller at Bruce than at Pickering despite the 50% higher reactor power of the Bruce units.

An advantage of the vacuum system over the pressure suppression system is the reduced requirement on leak tightness, because of the shorter time for which the over-pressure exists after a LOCA.

Operational Features

Detailed operation of vacuum containment will not be discussed in this course but some of the basic features are discussed below.

During normal operation, the vacuum building is maintained at 10 kPa(a) pressure, and the reactor building and pressure relief duct up to the pressure relief valves is kept subatmospheric (-0.3 kPa(g) PNGS, -2.5 kPa(g) BNGS) to minimize outleakage. The D₂O vapour recovery system maintains this subatmospheric pressure.

Containment system operation, ie, the opening of the pressure relief valves and subsequent onset of dousing, is triggered by high pressure in the boiler room/reactor vault area. The pressure rise itself will open the pressure relief valves (typically at 4 kPa(g)) in the pressure relief duct. No pressure sensing instrumentation therefore has to be relied upon for the opening of the pressure relief valves under a loss of coolant accident condition. Typical pressure transients in the vacuum building and in the reactor building are shown in Figure 5.

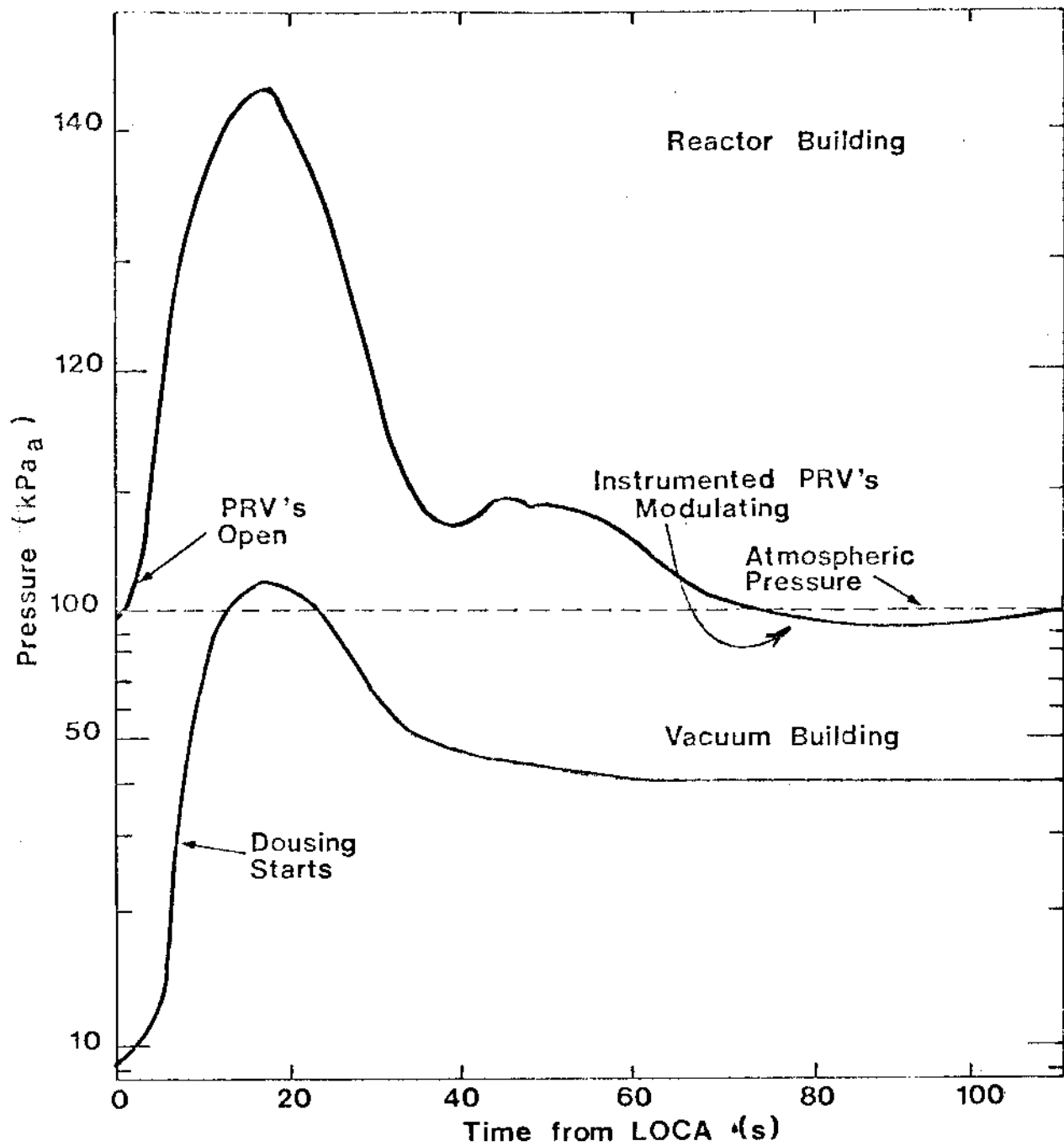


Figure 5: Typical Pressure Transients in Reactor and Vacuum Buildings Following a LOCA, (50% HT D₂O Loss).

As the pressure rises in the vacuum building due to the entrance of steam and air, dousing begins by syphoning action when the vacuum building pressure is large enough (~ 40 kPa(a)). Pressures in both the vacuum building and reactor building peak ~ 20 to 30 seconds after the event begins (depending on the size of the LOCA) then decrease. Within a few minutes the pressures should stabilize in the reactor building and vacuum building. When the reactor building pressure falls back to ~ 10 kPa(g) most of the pressure relief valves close. The remaining pressure relief valves (designated as instrumented PRV's) can be opened and closed by remote manual control to enable the pressure in the reactor building to be maintained slightly below atmospheric pressure. This can be done using the remaining vacuum in the vacuum building which should be below atmospheric pressure.

The final subatmospheric pressure of the vacuum building will depend on the amount of D_2O steam released in the LOCA and the amount of condensation achieved by vacuum building dousing. The more steam released, the higher the final vacuum building pressure will be.

III. IMPORTANT CONTAINMENT CONSIDERATIONS

Some important general features of containment are now discussed:

(a) Types of Containment Penetrations

(i) Permanently Installed Equipment Penetration

The concrete and steel containment structure has to be penetrated by a number of items. These include:

- (a) various permanently installed equipment supplies such as service air, instrument air, electrical power and control cables.
- (b) piping connections and process parameter instrument lines (Bruce) for numerous systems located partially inside containment.
- (c) system components such as primary pumps and boilers, eg, Bruce NGS-A.

All these penetrations have specially designed seals to maintain containment integrity, ie, prevent leakage. For example the large penetration at Bruce for the steam generators, shown in Figure 6, is located around the tube sheet area of the boiler by a specially designed seal.

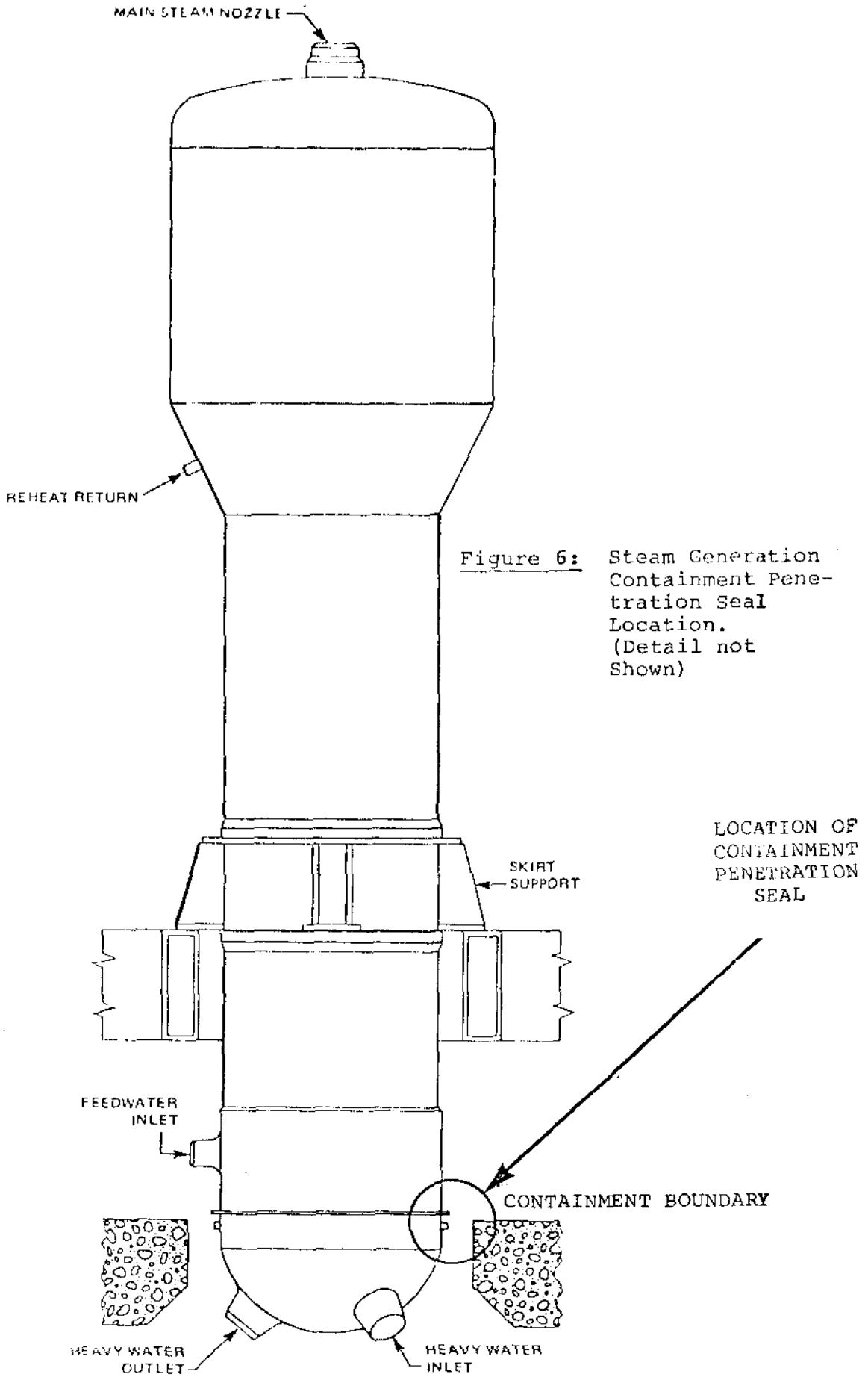


Figure 6: Steam Generation Containment Penetration Seal Location. (Detail not Shown)

LOCATION OF CONTAINMENT PENETRATION SEAL

CONTAINMENT BOUNDARY

Note that the boiler tubes containing HT D₂O are physically outside containment, and that the tubes themselves are the containment envelope at that location. This is considered acceptable as a large LOCA due to catastrophic rupture of large numbers of boiler tubes simultaneously is extremely unlikely.

At Pickering, the main steam lines and boiler feedwater inlet lines penetrate containment. Even though boiler tubes here are physically still inside containment, large scale boiler tube rupture would, as at Bruce, effectively violate the containment principle, by allowing HT D₂O and possibly fission product activity to leak into the steam-feedwater loop outside containment. The only way to eliminate such a path through containment would be to place the whole steam-feedwater system within containment. Obviously this is not practical nor, fortunately, necessary.

In the case of hot high pressure heat transport system process parameter instrument lines at Bruce, their penetration of containment also appears to violate the containment principle. However these lines are considered to produce only minor leaks in the event of a rupture. In order therefore to have accessibility to them without having to enter containment and also to minimize the probability of contamination spread outside containment they are located in instrument rooms with closed doors, outside containment.

(ii) Equipment and Personnel Airlocks

The purpose of these is to provide for movement of personnel and equipment into and out of containment.

The airlocks form part of the containment envelope, and consist of a pair of doors with inflatable seals, separated by a passageway. Electric and/or pneumatic interlocks allow one door only to be opened at one time, the other remaining closed to maintain containment integrity.

The closed or open status of airlock doors is monitored in the control room. A break of containment via an airlock door fault would be indirectly indicated by a decrease of reactor building ΔP with respect to atmospheric pressure.

(iii) Fuel Bundle Transfer Into and Out of Fuelling Machine and Fuelling Machine Transfer Into and Out of Reactor Vault

New fuel bundles are transferred into the fuelling machine from the new fuel bundle loading mechanism, and irradiated fuel bundles are transferred out of the fuelling machine into the irradiated fuel transfer mechanism. At each of these mechanisms, provision is made by means of seals and interlocks so that containment is not violated during fuel transfer operations.

The fuelling machine service room is part of containment while the fuelling machine is in transit from the service room to the vault for refuelling. While the F/M is in the service area, the fuelling machine service room may or may not still be part of the containment system, depending upon whether there is a containment seal provided for this room.

(iv) Penetration of Containment by the D₂O Vapour Recovery System

The purposes of the vapour recovery system are:

- to recover D₂O leakage from reactor area atmosphere, and hence to reduce D₂O losses and tritium contamination in the D₂O areas.
- to maintain D₂O areas at a pressure less than non-D₂O areas by exhausting dried air to the contaminated exhaust stack.

There may be several recovery systems serving various D₂O areas, depending on station layout, eg, at Bruce there are reactor vault, fuelling duct, and central fuelling area vapour recovery systems. Each system consists of a loop of ducting from the containment area being dried, to the vapour recovery driers, and back to the dried areas (Figures 7 and 8). Under normal operation, a continual exhaust to atmosphere, via the contaminated exhaust stack, using a purger or exhaust drier keeps pressure within the dried areas slightly less than atmospheric pressure. This minimizes outward leakage of activity. The vapour recovery system penetrates containment and because of this the system isolation points (dampers/valves) automatically close in order to isolate containment from the environment, or

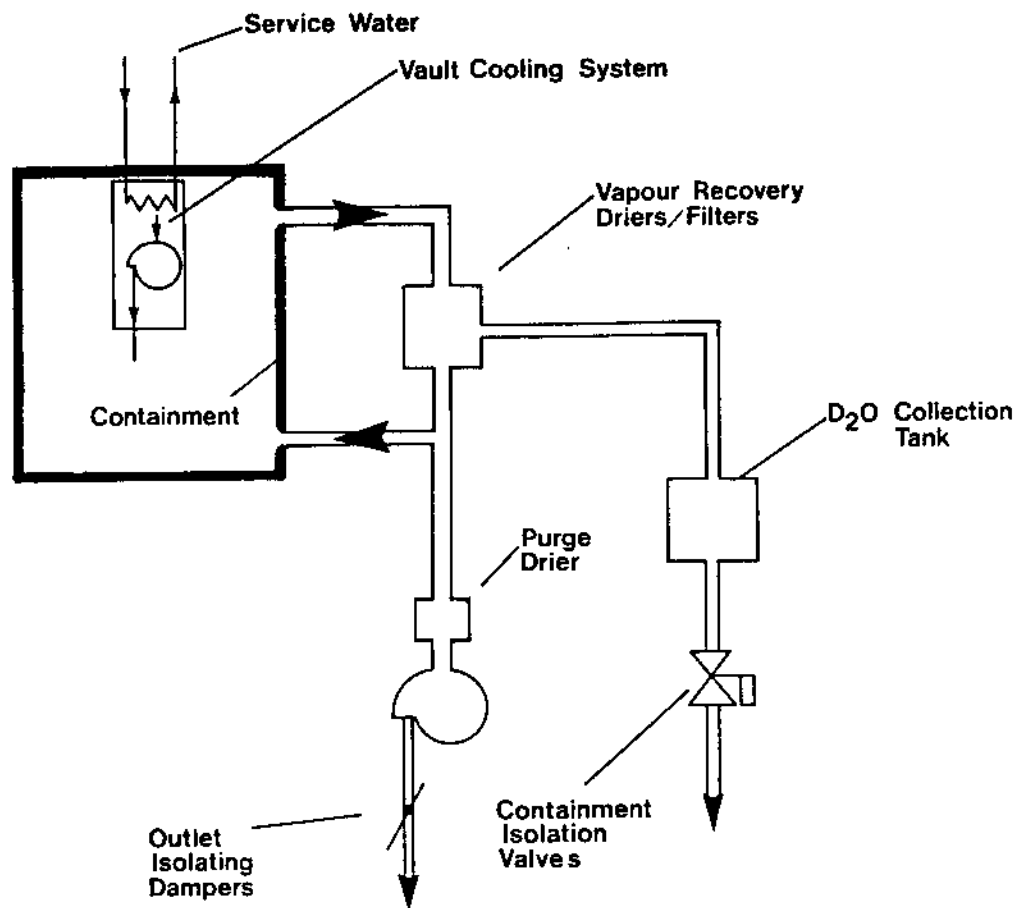


Figure 7: Relationship of D₂O Vapour Recovery and Vault Cooling With Respect to Containment (Bruce NGS).

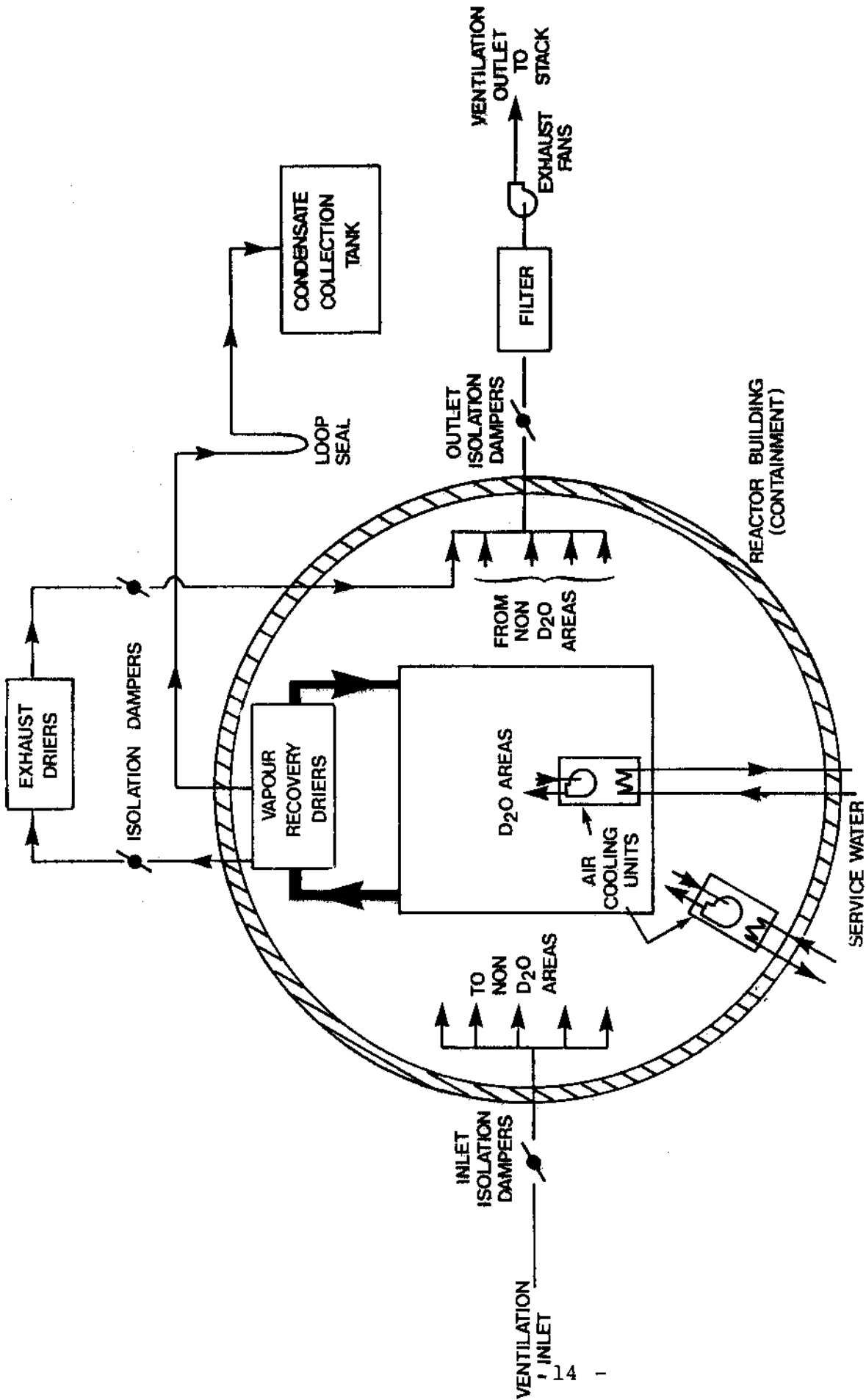


FIGURE 8: SIMPLIFIED SCHEMATIC OF CONTAINMENT VENTILATION, COOLING, AND VAPOUR RECOVERY SYSTEMS AT PICKERING GS

conditions which could release activity to the environment. This feature, referred to as containment "button up" or "box up" is discussed in more detail in (b) below.

(v) Penetration of Containment by the Reactor Building Ventilation System (Pickering)

Under normal operating conditions, the reactor building ventilation system, by means of exhaust fans, circulates air through the non-D₂O areas on a once-through basis, and exhausts it up the stack. These non-D₂O areas are normally accessible during operation. Exhaust fans, see Figure 8, maintain the non-D₂O areas at slightly less than atmospheric pressure to minimize out-leakage, although the pressure will still be greater than that in the D₂O areas. This system then is open to the environment during normal operation, see Figure 8.

Under conditions which could release activity to the environment, the ventilation system will be isolated from the environment by the closing of inlet and outlet isolation dampers in order to box up containment. Details of this are discussed in (b) below.

(b) Containment Box Up
Bruce NGS (Figure 7)

At Bruce NGS, because the vapour recovery system penetrates containment, automatic closing of the recovery system isolation points is necessary when any of the following occurs:

- high containment activity
- high containment pressure
- loss of stack activity monitoring.

The isolation points are dampers⁽ⁱ⁾ at the exhaust to atmosphere on the purge drier outlet and valves⁽ⁱ⁾ on the drier condensate line, leading to the condensate collection tank. Note that the driers, condensate system, and system piping up to the isolating points are an integral part of containment. On containment box up, the above dampers and valves automatically close.

(i) Usually two in series are used for reliability.

Pickering NGS (Figure 8)

At Pickering NGS the principle of box up is the same as at Bruce NGS but design differences result in different isolation points. This is because, unlike Bruce, the Pickering ventilation system, which serves the non-D₂O areas within containment, shares its exhaust with the vapour recovery system exhaust driers. Also the main driers are physically inside the reactor building containment structure. However, the containment envelope extends to the isolation dampers in the inlet and outlet lines connected to the exhaust driers, located physically outside the reactor building. In addition, isolation for the condensate system is provided by a U loop water seal, which is always boxed up in the sense that the loop seal is always intact. This seal is designed to withstand pressure surges associated with LOCA's.

On containment box up, the following isolation devices close:

- inlet and outlet dampers in the exhaust drier loop external to the reactor building.
- outlet isolation dampers leading to the filter on the combined vapour recovery/ventilation exhaust.
- inlet isolation dampers of the ventilation system.

(c) Reactor Building Cooling System (Vault Cooling System)

This system is designed to cool and dehumidify the reactor building atmosphere, particularly in the reactor vault. Typical maximum temperature and dew-point limits are ~40°C and ~-18°C respectively. Atmospheric heating is via heat losses (sometimes called ambient losses) from hot equipment such as boilers, pumps, motors and pipes.

The system, located inside containment, consists of air cooling units cooled by service water and supplied with air by fans. During normal operation, no condensation is expected on the coolers, although high D₂O and H₂O leakage rates will result in some condensation.

During a LOCA, however, this cooling system has a containment function, namely to provide a heat sink in the reactor building to condense steam. It can remove typically up to 1% reactor thermal power. This is adequate to match decay heat a few hours after shut-down. This heat sink would be particularly important in the absence of any other heat sink, eg, the ECCS heat exchanger, even though the heat transfer from the fuel to the vault atmosphere, and hence to the coolers, is not very efficient. Therefore any reduction in the vault cooling capacity is considered to contribute to containment unavailability, see below.

(d) Containment Unavailability

Safety systems, of which containment is an example, are required to meet certain unavailability targets. For example, at Bruce the target is 10^{-3} . The units of this number are years per year. Therefore this means containment should not fail (be unavailable) for longer than 10^{-3} years (~ 8 hours) in one year.

A containment failure (sometimes called a loss or breach of containment) is an event which would impair the operation of containment during a LOCA. Containment failure during a LOCA might result in the release of activity to the environment or to the station accessible areas.

Highly reliable containment is thus very important. Examples of containment failure are given below. Notice that not all these failures specifically involve leakage as such.

Examples of containment failures are:

- failures of automatic containment isolation mechanisms to button up (note this may be due to failure of activity monitors and containment pressure switches, as well as to damper or valve failure).
- failure of airlock integrity allowing air passage through the airlock.
- failure of more than a specified number of pressure relief valves to operate.
- loss of dousing capability.
- leak paths in containment.
- loss of reactor vault cooling capability.

Containment components and subsystems are tested periodically to demonstrate that the containment reliability target is met. Examples of such tests are the airlock pressure test, damper leak test and pressure relief valve tests. Any actual leaks not detected by such routine tests may be detected by a rise in containment pressure, which is monitored in the control room.

ASSIGNMENT

1. State the importance of the following systems with regard to containment:
 - reactor building D₂O vapour recovery system
 - reactor ventilation system
 - reactor building cooling system.
2. For your own plant, locate on a flowsheet the containment isolation points for the systems of question 1.
3. State one specific example of containment failure which could lead to a hazard
 - (a) to the environment, and
 - (b) to plant equipmentif a LOCA occurred.
4. State what the containment reliability target is for your own plant. From your station's last 4 quarterly reports, find what the sources of containment unavailability were, and what the actual unavailability was.
5. List three conditions which initiate containment button up.

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