

24 Emergency Coolant Injection & Containment

24.1 Introduction

Each CANDU has four special safety systems. The two shutdown systems, SDS#1 and SDS#2 have been discussed. This module introduces the emergency coolant injection system (ECIS) and the containment system. The plant design includes these four special safety systems to protect the public from a harmful radiation release.

In normal operation, five barriers stand between the main source of radiation and the public. The ceramic fuel pellets hold about 95% of the fission products. The fuel sheath contains the free fission product inventory. The heat transport system contains fission products released from failed fuel.

The containment system is the fourth barrier to release of radiation. Its purpose is to make and protect an envelope that holds radioactive material released from the heat transport system. This limits public exposure to radioactivity when the first three barriers fail.

The fifth barrier to public radiation exposure is the 1 km exclusion zone around each reactor core. This zone allows dilution of radioactive material that escapes from the containment system.

These five barriers protect the public if the reactor power is controlled, the fuel cooled and the radiation contained.

Rapid shutdown protects the first three barriers (pellet, sheath and piping). In most upsets, a rapid power reduction quickly matches the fuel heat output to available cooling. This limits the amount of steam generated. It keeps the system pressure from putting the piping at risk. The fuel stays wet and does not release fission products.

Some accidents do release fission products. For these accidents, rapid shutdown limits the fuel failures and radiation release. This limited release helps the two final barriers, containment and dilution, to do an effective job.

The emergency coolant injection system (ECIS) protects the fuel and heat transport system boundary when normal cooling fails. Its purpose is to refill the heat transport system and keep it full after a loss of coolant accident (LOCA). This sets up an alternative heat flow path for removing decay heat.

Both the emergency coolant injection system and the containment system must operate under conditions caused by a loss of coolant accident. Before we describe these systems, here is a brief description of a LOCA.

Coolant escapes from the heat transport system if pipes break, or pump seals fail. Various sizes of failure are possible.

For a small HTS break, the pressure regulating equipment keeps the heat transport system pressure normal. This is called a leak. The D₂O recovery system, is designed to cope with leaks. In a loss of coolant accident the heat transport pressure inevitably decreases by itself.

Here is an example. Just before noon on August 1, 1983, pressure tube G16 on Unit 2 at Pickering A suddenly split. Pressure in the annular space burst an annulus bellows. Coolant escaped slowly past the journal bearing through the break in the bellows.

Less than 1½ hours after the pressure tube ruptured, the operators had shut down the reactor, cooled the heat transport system and reduced its pressure. The operators controlled the HTS pressure reduction during this time. The operators managed a controlled shutdown, bringing in reserve D₂O from other units. None of the special safety systems was required. If they had left the system to itself, pressure would have dropped gradually on its own and special safety systems would have operated.

This example of coolant loss is near the boundary that distinguishes a LOCA from a leak. The pressure could not be kept high and would have fallen naturally, as in a LOCA. However, because pressure fell slowly; the operators controlled it, as in a leak.

During a LOCA, low-pressure produces steam in the heat transport system. If this condition persists, fuel fails and releases fission products through the break. A large pipe break (for example, a reactor header or pump suction piping) causes the poorest cooling conditions and the most fuel failures. In these accidents some coolant reverses flow to travel towards the low-pressure at the break. Depending on the break size and location, coolant flow stops briefly in some channels.

Emergency cooling limits the release, helping maintain the effectiveness of the final two barriers. For a small LOCA, rapid shutdown and ECIS operation may prevent any fuel failures.

24.2 Summary Of Key Ideas

- Four special safety systems protect the public from an accidental radiation release. These are SDS#1, SDS#2, ECIS and Containment.
- Rapid reactor shutdown matches heat output to available cooling, protecting the first three barriers to radiation release. These barriers are the fuel pellet, the fuel sheath and the heat transport pressure boundary.
- Rapid shutdown also helps the last two barriers (the containment system and the exclusion zone), by limiting the amount of radioactive material released.
- In a loss of coolant accident (LOCA), heat transport system pressure falls. Steam produced in the heat transport system impairs fuel cooling. On a large break, fission products escape into containment.
- The purpose of the emergency coolant injection system (ECIS) is to refill the heat transport system after a LOCA and keep it full. This sets up an alternative heat flow path for removing decay heat.
- The purpose of the containment system is to make and protect an envelope that limits the release of radiation to the environment.

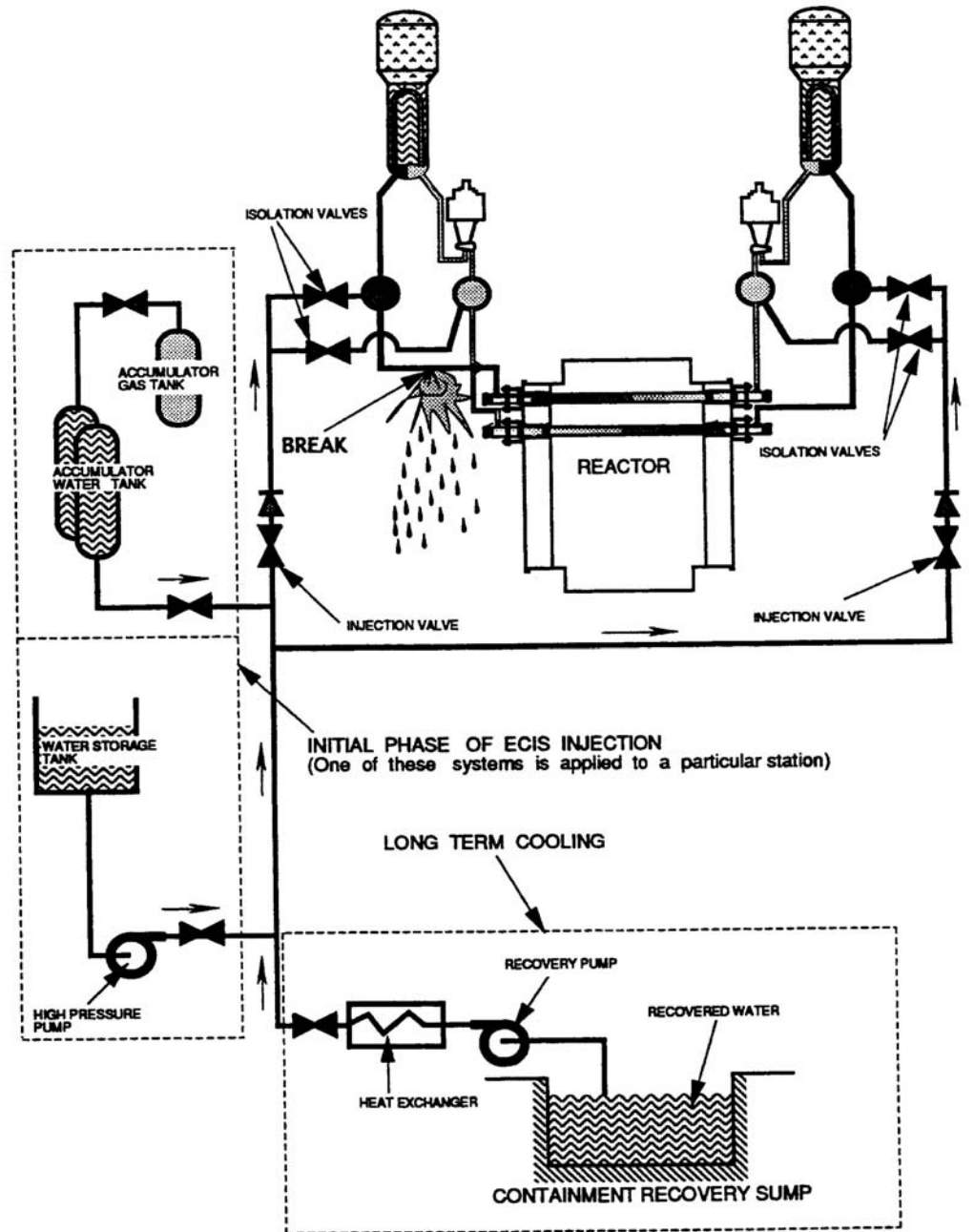


Figure 24.1
Simplified Emergency Cooling Injection System

24.3 Emergency Coolant Injection

On a LOCA, conditions in the reactor core or heat transport system trip the emergency shutdown systems. The emergency coolant injection system (ECIS) can remove decay heat, not fission heat. Without shutdown, high-pressure steam in the core may prevent effective injection of emergency cooling water. Heat removal will be inadequate and many fuel elements will fail.

Figure 24.1 shows the main equipment in a typical emergency coolant injection system. In a multi-unit station, a single system protects all the units. Figure 24.1 shows injection of cooling water into one unit. Some stations use gas pressure to push H₂O from the water tanks into the reactor. Some stations use high-pressure pumps for high-pressure injection.

Low HTS pressure automatically in conjunction with a second parameter triggers the emergency coolant injection system. The use of two parameters to initiate the system prevents spurious injections. The ECIS signal opens the isolation valves (also called injection valves) of the affected unit. These valves separate the ECIS H₂O from the coolant D₂O. The signal also connects the high-pressure source that forces the light water into the reactor inlet and outlet headers. Injection begins when the HTS pressure is lower than the ECIS injection pressure.

The ECIS injects light water because D₂O is too expensive to keep on hand for an emergency that should never happen. After a LOCA, upgrading of coolant would be one of many problems requiring solution before the unit could be returned to use.

The ECI systems in different stations are significantly different. In fact, there are two names used in the stations: ECI and ECC for emergency core cooling.

24.3.1 The Small LOCA

On a small loss of coolant accident, heat transport system pressure falls slowly because the leak rate is slow. The coolant begins to boil and the fuel channels gradually fill with steam. While the coolant boils, the system pressure falls only if the temperature drops.

For injection to start quickly, heat must be removed from the system. Large valves on the boilers open automatically to release steam, reducing the boiler temperature. The operator can open the steam valves from the control room if they do not open automatically. Crash cooling of the boilers causes rapid transfer of heat from the coolant to the boiler water. This quickly reduces the heat transport system

temperature and pressure and injection begins. Cool water refills the system and rewets the fuel. The main heat transport pumps circulate the mixture of H₂O and D₂O to the boilers, which remove most of the decay heat.

Some steam and hot water escape from the break. This water collects in the ECIS recovery sump. If necessary, the recovery pumps return this water to the system to keep it full. The recovery heat exchangers cool the water before returning it to the HTS.

24.3.2 The Large LOCA

On a large loss of coolant accident, the main heat sink is the large amount of hot water and steam that escapes through the break. Pressure and temperature of the heat transport system drop quickly with or without boiler crash cooling.

The break is the lowest pressure point in the system. Coolant moves from the inlet and outlet headers towards the break. Water injected at the headers passes over the hot fuel and rewets it. A mixture of light and heavy water and steam escapes through the break.

For long-term fuel cooling, the operator sets up a recirculation cooling loop. The loop includes the heat transport system piping, a recovery sump, recovery pumps and recovery heat exchangers. Water cools the fuel and spills from the break to the containment floor. Hot water collects in the recovery sump. The recovery pumps return the recovered water to the reactor headers through the heat exchangers that cool it. This cooling loop can operate for an indefinite time.

On a big break the HTS cools down faster than the boilers. Crash cooling stops the boilers from dumping extra heat into the heat transport system.

The high-pressure water supply tanks may empty before water collects in the recovery sump. To protect against this, a low-pressure water supply injects water after high-pressure injection ends and before recovery begins. The low-pressure supply consists of the recovery pumps, drawing water from an emergency storage tank and pumping it to the reactor headers.

24.4 Summary Of Key Ideas

- SDS#1 or SDS#2 shut down the reactor on a LOCA. This permits effective ECIS operation.

- ECIS equipment includes a high-pressure water supply, a low-pressure water supply, a recovery system and isolation/injection valves.
- Gas pressure supplies high-pressure injection to the reactor headers at some stations. Other stations use high-pressure pumps.
- The low-pressure water supply to the headers uses the recovery pumps, drawing water from an emergency storage tank.
- For long term cooling, recovery pumps deliver water to the headers from the recovery sump via the recovery heat exchangers.
- ECIS operation begins automatically when HTS pressure fails. The ECIS signal opens the isolation/injection valves and opens the valves that connect the high-pressure source.
- When the ECIS system triggers, large steam valves on the boilers open automatically to begin crash cooling. This is particularly important on a small LOCA, where the boilers are the main heat sink. The break is the main heat sink on a large LOCA.
- The control room operator can start ECIS operation and crash cooling from the control room if they do not trigger automatically.

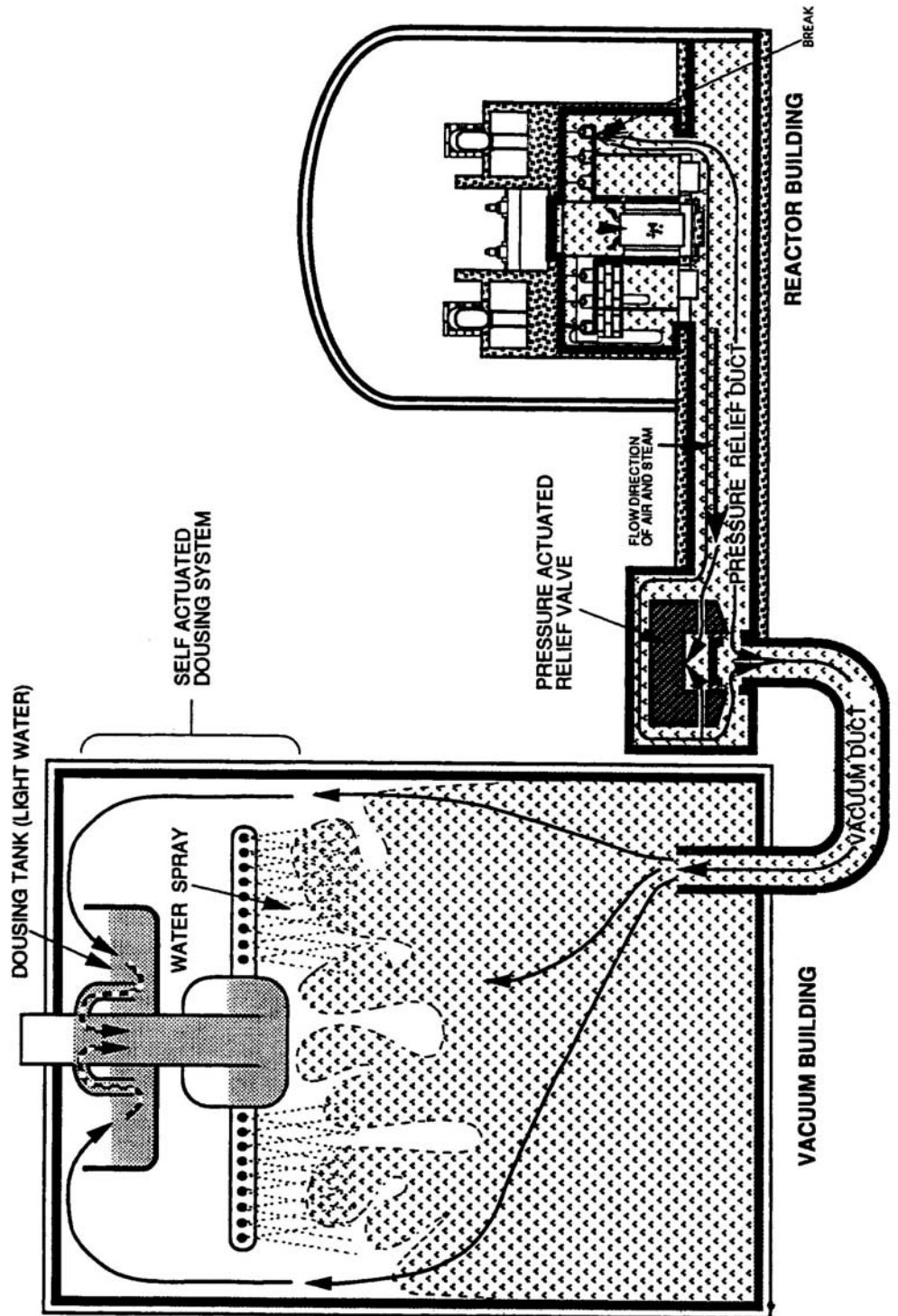


Figure 24.2
The Vacuum Containment Concept

24.5 Containment

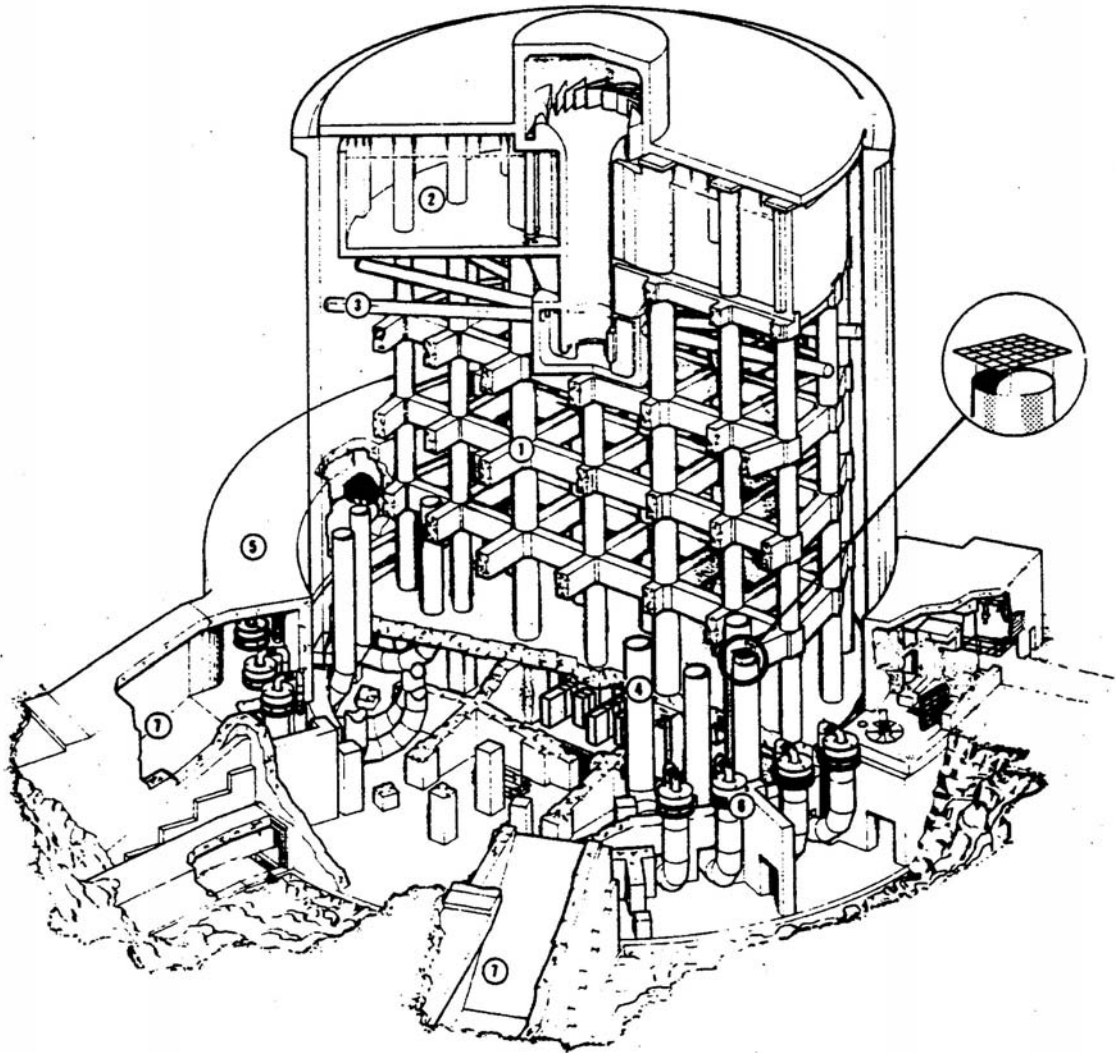
The containment system is actually a group of systems. First there is the envelope itself. This surrounds all nuclear systems that could release radiation. On a LOCA signal, the containment envelope boxes up or buttons up. That is, penetrations through the envelope close to prevent escape of radioactive material. Various energy sinks protect the envelope from over pressure. A dousing system condenses steam and cools the containment atmosphere. Air coolers remove heat. A clean air discharge system can be used to filter and discharge air, allowing relief of high-pressure in the building.

There are two different containment designs for CANDU reactors: the pressure suppression containment system and the negative pressure containment system.

Single unit stations use a pressure suppression containment system (Figure 24.6). The containment structure, which is the reactor building itself, complies with the pressure vessel code standards. It has a very low leak rate under pressure.

Units in a multi-unit station share a vacuum building. The vacuum building is part of a negative pressure containment system. Figure 24.2 shows that the vacuum building and reactor building are each part of the containment envelope. After a LOCA, pressure inside this envelope is sub-atmospheric, preventing leakage out.

Negative pressure systems and pressure suppression systems both limit radiation release to the public. The cost of negative pressure containment is reasonable when several units share a vacuum building. Pressure suppression containment requires reinforcement of each unit. This is less expensive than a vacuum building for a single unit. It is less cost effective for a multiple unit station.



- 1 Internal Structure
- 2 Emergency Water Storage Tank
- 3 Distribution and Spray Headers
- 4 Vacuum Duct
- 5 Valve Manifold
- 6 Pressure Relief Valve
- 7 Pressure Relief Duct

Figure 24.3
Vacuum Building, Relief Valves and Dousing

24.5.1 Negative Pressure Containment

Figure 24.4 shows a pressure relief duct connecting four units to a vacuum building via several vacuum ducts. (The pressure relief duct is on the reactor building side of the relief valves. The vacuum ducts are on the vacuum building side of these valves.) In some stations, the connecting duct runs underground and is not visible. Figure 24.3 show this arrangement, with the relief valves in a valve manifold surrounding the vacuum building.

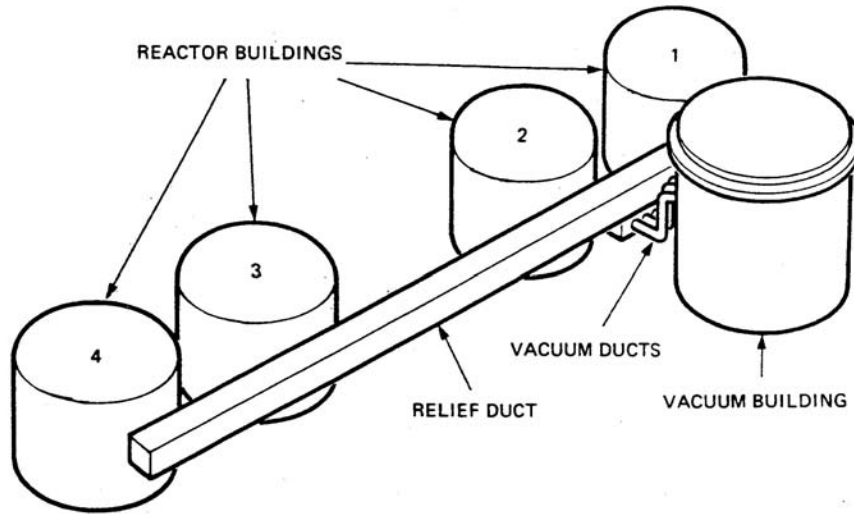


Figure 24.4
Multi-Unit Containment

Some stations with negative pressure containment systems put as much equipment as possible inside the containment envelope. This reduces the number of penetrations but results in a large containment volume. A large containment volume requires a large vacuum building.

Other stations place as much equipment as possible outside containment. This gives better equipment access and reduces the containment volume. It also increases the number of containment penetrations where radiation could leak. Figure 24.5 shows these differences.

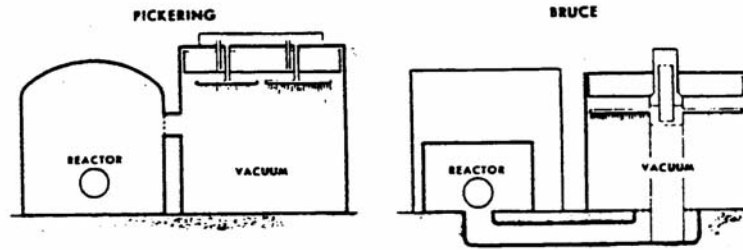


Figure 24.5
Sizes of Containment for Pickering & Bruce Stations

On a LOCA, pressure inside containment rises. High-pressure lifts the relief valves that connect the pressure relief duct to the vacuum building via the vacuum ducts. Heated air and steam escape into the low-pressure vacuum building. Increased pressure forces water from the dousing tank into the dousing spray headers. The dousing spray cools the air and condenses steam. Within a minute or two the pressure inside containment is again lower than the pressure outside.

The high-pressure of the accident opens the relief valves and starts dousing. A LOCA signal boxes up the containment envelope and shuts off the system that draws vacuum in the vacuum building.

In addition to the valves that are opened by the pressure of a LOCA, there are large and small control valves that modulate for long-term pressure control.

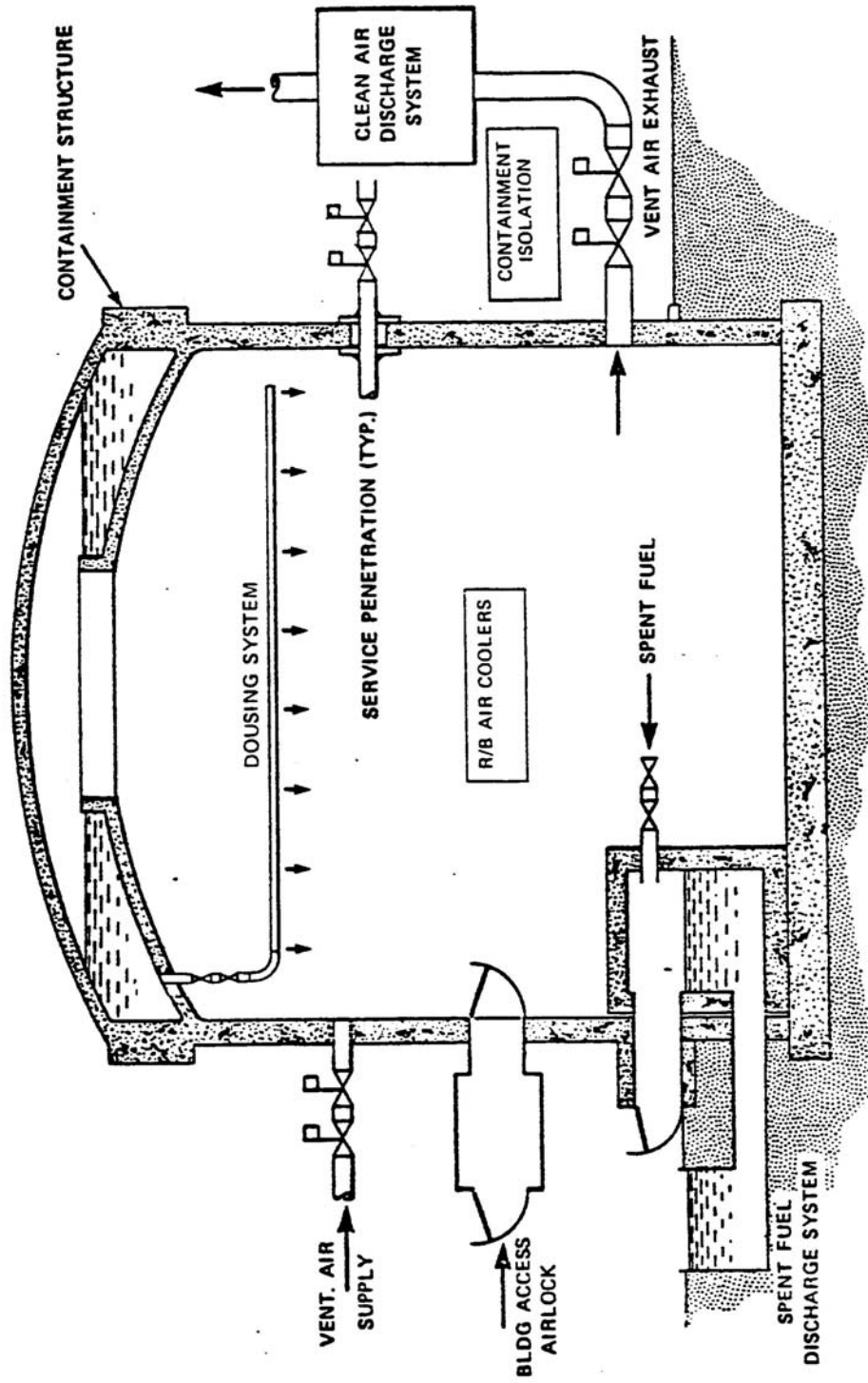


Figure 24.6
A Pressure Suppression Containment System

24.6 Pressure Suppression Containment

Figure 24.6 shows a pressure suppression containment system. The reactor building walls are reinforced concrete, lined with an epoxy liner. The leak rate from this structure is low if the pressure does not rise too high.

The dousing water tank is in the top of the reactor building. A LOCA signal boxes up the containment structure and opens the dousing valves. Dousing removes heat and condenses the steam. This helps lower the pressure and keeps the leak rate small.

24.7 Summary of Key Ideas

- The containment system is a group of systems. First there is the containment envelope and the system that boxes it up. Then there are energy sinks (dousing, air coolers and clean air discharge) that protect the envelope from damage.
- Both negative pressure containment systems and pressure suppression containment systems protect the public from release of radiation. Single unit stations use a pressure suppression system. Multi-unit stations share a vacuum building containment system.
- Negative pressure containment uses a vacuum building. Pressure relief into the vacuum building combines with dousing to drop pressure. Inside the containment envelope, the pressure is soon sub-atmospheric. This stops radiation leakage to the environment
- Pressure suppression containment uses a lined, reinforced concrete structure. This structure has a low leak rate when under pressure. Dousing helps keep a low leak rate.
- With negative pressure containment, pressure from the LOCA opens the pressure relief valves and causes dousing. The LOCA signal boxes up the envelope and turns off the vacuum system.
- With pressure suppression containment, the LOCA signal triggers box-up and dousing.

24.8 Assignment

1. What are the four special safety systems?
2. How does rapid shutdown of the reactor help:
 - a. the emergency coolant injection system do its job?
 - b. the containment system do its job?
3. Describe how the emergency coolant injection system helps prevent the escape of radiation to the environment.
4. List the various systems that make up the containment system.
5. Describe the way each system in question helps protect the public from radiation exposure.
6. Give the major differences between a vacuum building containment system and a pressure suppression containment system.
7. Outline the immediate response of the emergency coolant injection system and the containment system to a large LOCA.
8. Describe the medium and long-term response of the emergency coolant injection system when there is a LOCA.

