Reactor Boiler and Auxiliaries - Course 133

CONTAINMENT SYSTEMS

Containment systems are provided specifically to cater for a rupture of the HT system pressure boundary and are designed 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 around the "nuclear" components of the HT systems and the criteria for determining the envelope effectiveness is the time-integrated leak rate for the period of a pressure excursion.

As a result of the increased size of our units from the early days of NPD design and the introduction of the multi-unit station concept, safety philosophy has changed over the years and has resulted, in Canada, in three different containment systems which are used in our plants. These are:

(a) Pressure Relief System
(b) Pressure Suppression System
(c) Vacuum Containment System.

(a) Pressure Relief System

This system based on direct relief to atmosphere, Figure 1, utilizes a pressure relief duct and dousing and is used at NPD (and also at WRI, Whiteshell). It was acceptable in the early days due to the remote location and small size of the units.

There is no containment sphere which encloses the NPD reactor. Instead the whole of the primary system is contained within reinforced concrete structural and shielding walls. The reactor vault is designed to withstand 70 kPa(g) and the boiler room 35 kPa(g). A combined pressure relief duct and dousing system is installed to keep the pressures generated by coolant system rupture within these limits.

The pressure relief duct is necessary because in the time (nearly two seconds) between the actuation of the pressure switch and complete dousing, the steam from a large rupture could cause the internal pressure to rise above acceptable limits for the wall.

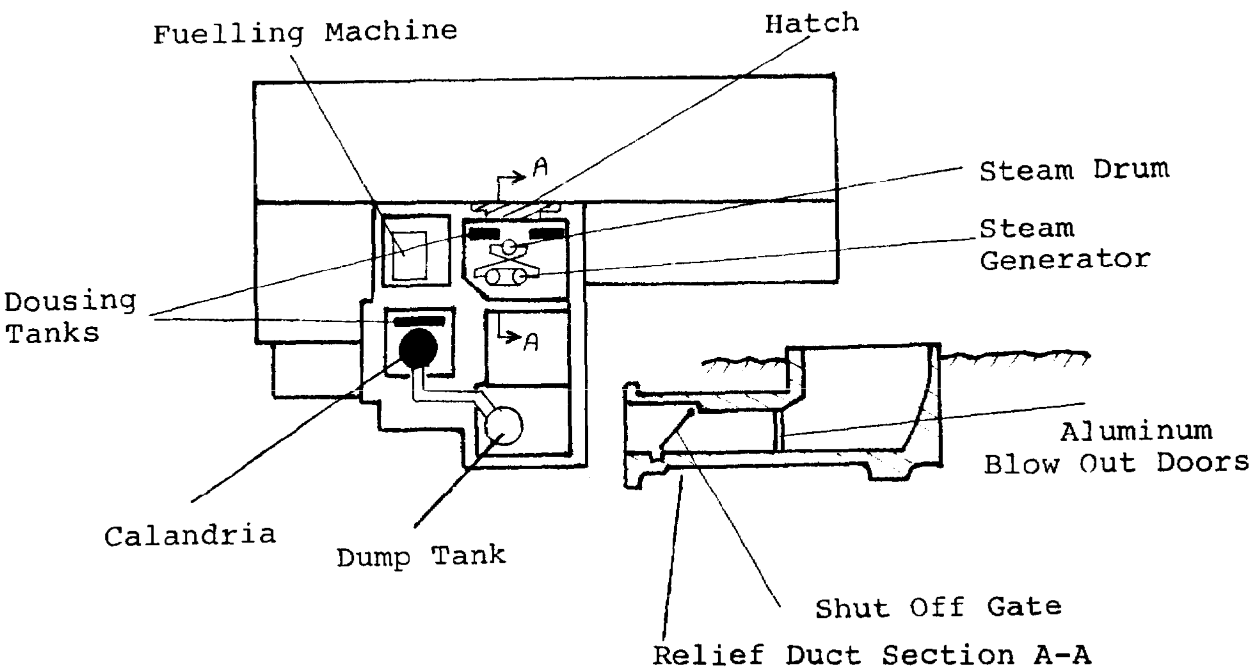


Figure 1 NPD Pressure Relief Containment

The rectangular relief duct is about 11 square metres in section and is normally closed off from the boiler room by a diaphragm which will rupture at 10 kPa(g). This diaphragm will contain a heat transport leak rate of up to 40 kg/sec. Downstream from the diaphragm is a horizontally hinged gate, the hinge being at the ceiling of the duct, with the gate normally flush with the ceiling. When the boiler room pressure reaches 10 kPa(g) dousing valves are actuated, the diaphragm ruptures, and after a ten second delay the gate closes under gravity. At the exit from the duct is a large pit, to deflect any discharge skywards. The principle behind this system is that the air discharged to atmosphere will be the very low activity air in the duct and that the gate will close before any high activity particles reach the duct.

The main dousing storage tank is outside the reactor building and contains 1,000 m^3 of light water. There are two spray systems fed from this dousing tank, one in the reactor vault and one in the boiler room as shown in Figure 1.

Due to its obvious drawback this system is not widely used throughout the world, although one variant on the direct relief scheme is used on some power reactors in Japan. Here very large graphite filters installed in a relief duct effectively filter out all active particulate matter while allowing passage of the steam/air mixture to atmosphere.

(b) Pressure Suppression System

After NPD was built the atmospheric pressure relief system it used was not considered acceptable for any further units. All future units, therefore, installed systems providing essentially complete containment following a loss of coolant accident. Of these units Douglas Point, Gentilly 1 and 2, and the 600 MW(e) (initially all single unit stations) use pressure suppression containment, in the form of a light water dousing system alone, with no pressure relief to atmosphere as at NPD.

To achieve this, at Douglas Point (Figure 2) the reactor building was built of thick (1.3 m) concrete walls with a correspondingly thick steel dome designed to withstand an internal pressure of 41 kPa(g) following the maximum possible escape rate of coolant flashing into vapour. To suppress the pressure surge following a LOCA, light water spray dousing from a 2,000 m^3 capacity storage tank in the top of the reactor building is utilized. The leakage rate out of containment here is limited to 2.4% of total volume/day at an internal pressure of 41 kPa(g).

The 600 MW(e) units utilize a similar system to Douglas Point all having their own individual self-contained dousing systems (Figure 3). To economize on the cost of a dousing water storage tank, the storage for the 600's is contained in the reactor building roof dome as shown. The leakage rate out of containment for these units is 0.5% of total volume/day at 124 kPa(g) pressure. Design pressure for the pre-stressed concrete containment is 124 kPa(g).

(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 plants using 600 MW(e) units committed at this time are for less than three units, hence vacuum buildings are not planned for these plants - Gentilly, Pt. Lepreau or Rio III.)

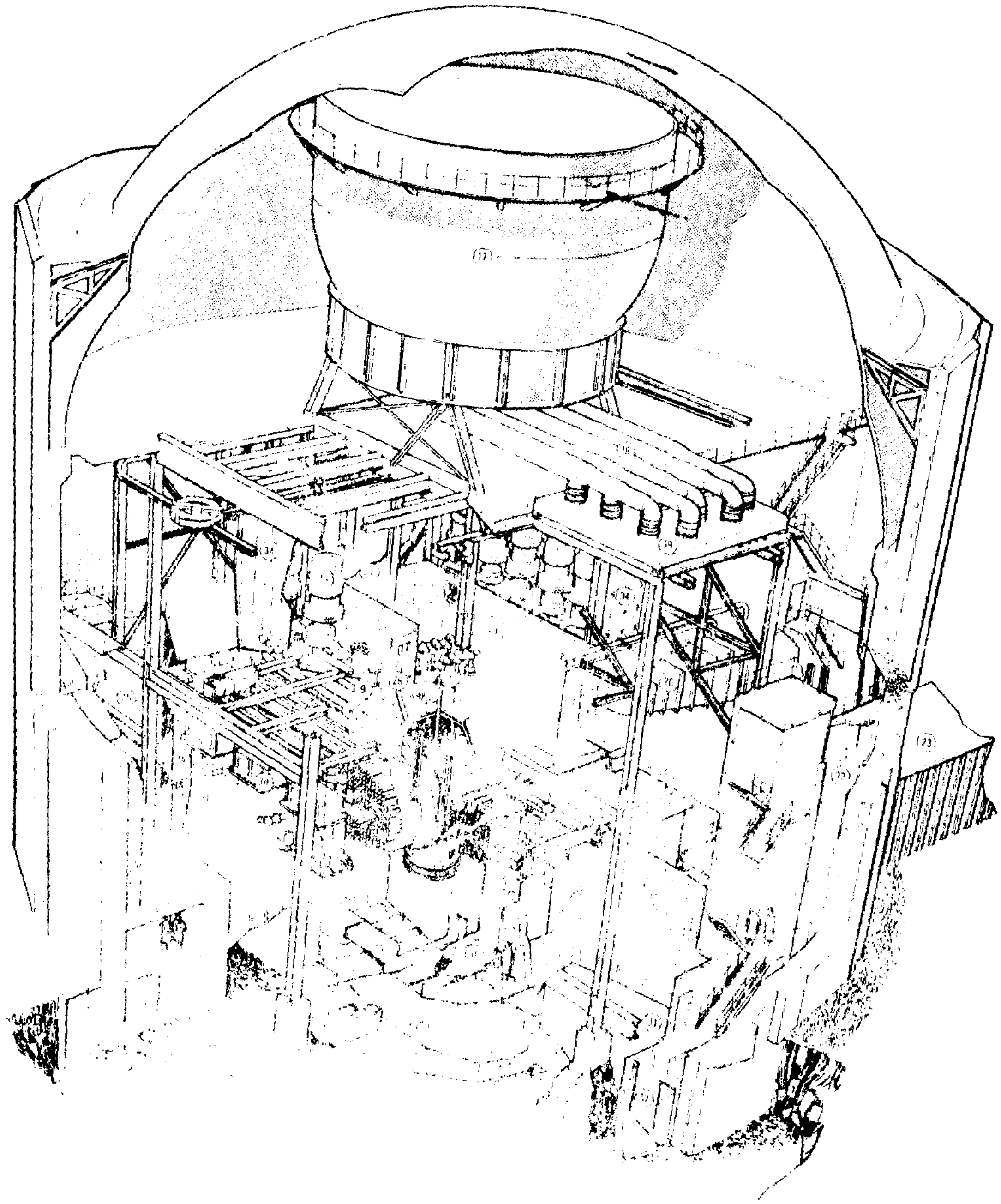
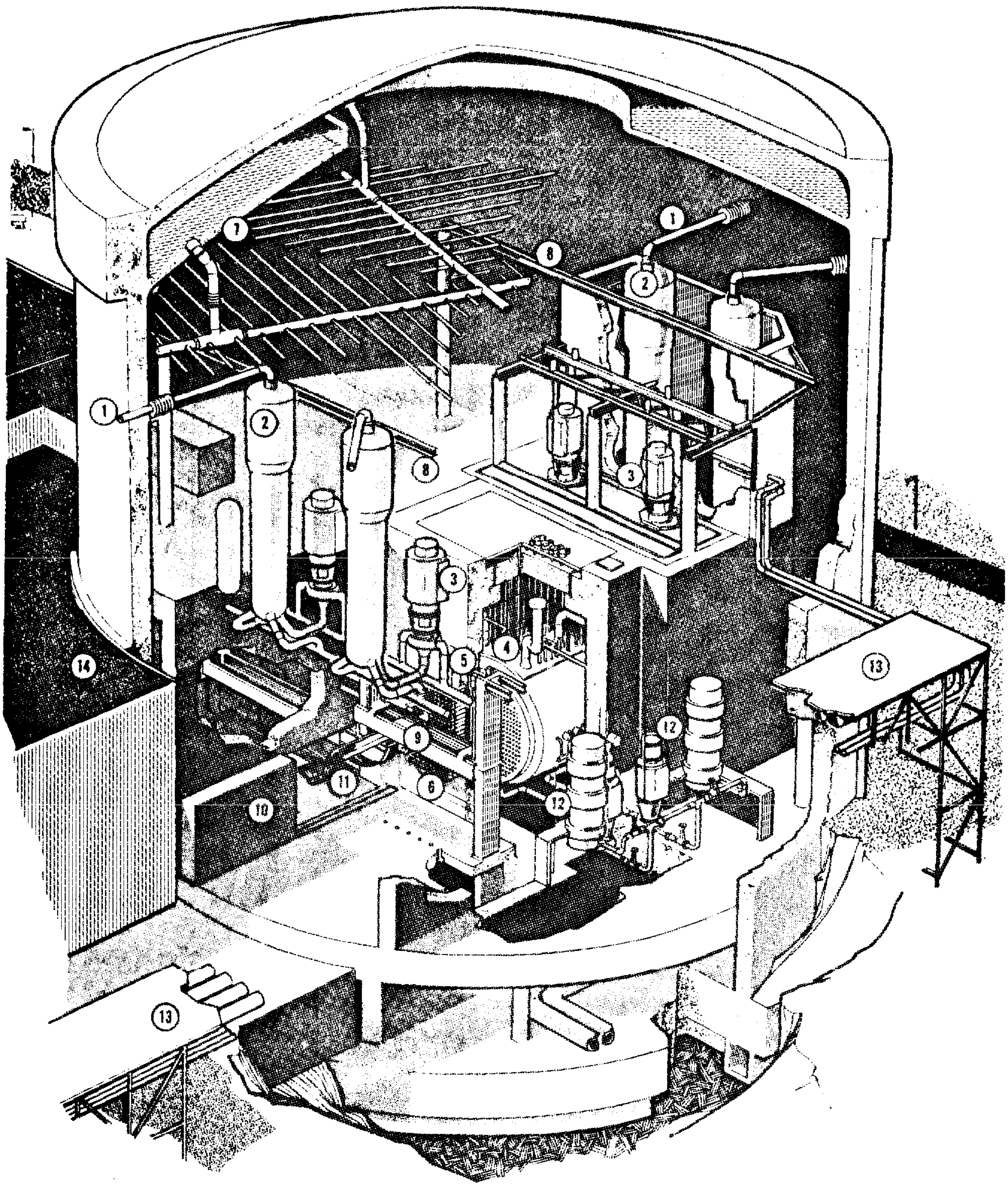


FIGURE 2 DPGS REACTOR BUILDING SHOWING DOUSING SYSTEM



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

FIGURE 3 REACTOR BUILDING CUTAWAY

600 MW(E) CANDU

This type of system is the one used almost exclusively around the world in other power reactor types, in particular the US PWR and BWR reactors, which usually combine light water dousing with the characteristic thick-walled concrete domed or spherical containment around the reactor.

(c) Vacuum Containment System

This system, a unique Canadian design, sometimes called a negative pressure containment system is a feature of our multi-unit stations. As mentioned above, for more than two units, multi-unit containment becomes more economical than single unit containment. The principle involved in negative pressure containment is that within a short time period (~30 seconds) 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 should take place. The complete system consists of the reactor buildings, the vacuum building, the pressure relief system, the vacuum system and the dousing system.

The reactor buildings at Pickering and Bruce use conventionally reinforced containment structures, cylindrical at PGS and rectangular at BGS (shown to scale in Figure 4) designed for 41 kPa(g) and 70 kPa(g) overpressure respectively. These

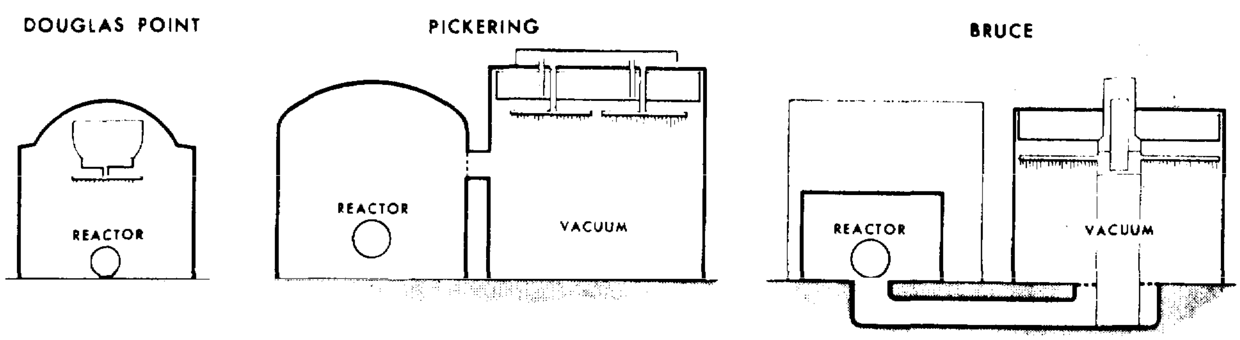


Figure 4 Containment Systems

buildings are joined by means of a reinforced concrete pressure relief duct to a large cylindrical vacuum buiding in each case. Figure 5 illustrates the overall Pickering A & B plant layout.

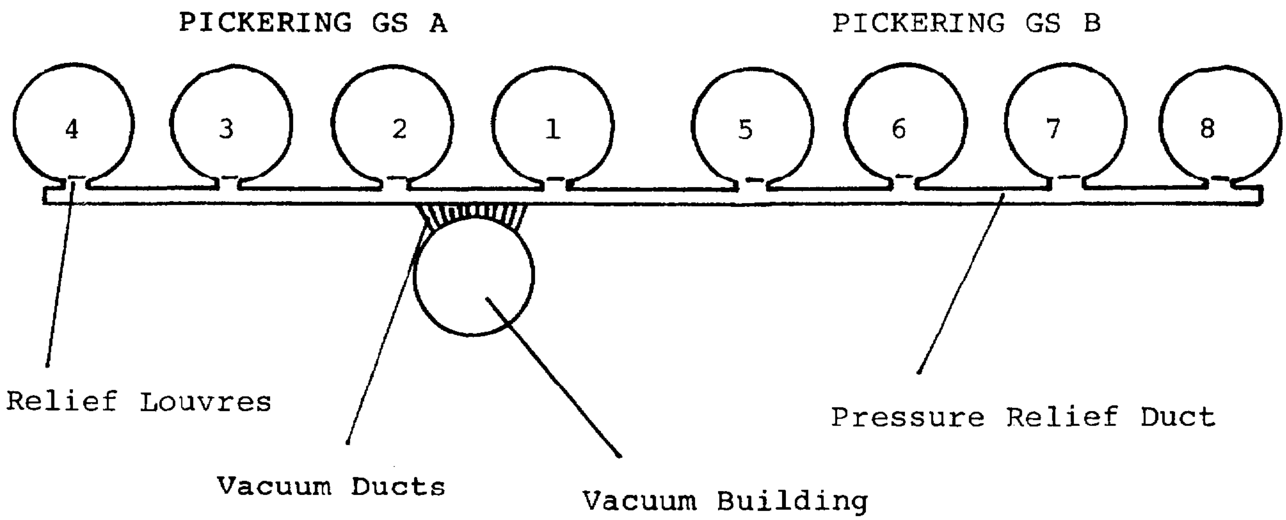


Figure 5 General Layout of the Pickering Vacuum Containment System

The containment volume at Bruce is seen to be smaller than at Pickering because the steam generators and some other equipment are located outside the containment at Bruce, unlike Pickering. Also at Bruce the D_2O steam discharge from a HT system failure is discharged downwards via an underground duct from the calandria vault to the vacuum building. The changes at Bruce resulting from these differences has then resulted in a rectangular rather than a domed reactor building and, in addition, the vacuum building can be smaller than for Pickering despite the 50% increase in reactor power. Any escaped D_2O steam will then carry less air with it into the vacuum building.

The main advantage in the vacuum system is the reduced requirement on leak tightness because of the lower time-integrated overpressure after a LOCA compared to the overpressure experienced in a single unit containment system. For instance, the leakage rate out of the vacuum building at Pickering is 2.7%/hr of the total volume at an overpressure of 41 kPa(g) and at Bruce it is 0.7%/hr of the total volume at the same overpressure.

The main disadvantage of the vacuum system is the loss of adequate containment capability for the remaining units of the plant following a LOCA in one unit. In principle use of the vacuum building does not mean shutdown of the entire plant (eight units at Pickering) because under normal operating conditions it is permissible, from reliability calculations, to run the station for one week per year with the vacuum system unavailable and so short periods of unavailability are permitted. However, in this case the AECB stipulate that two or more reactor buildings must be interconnected by blocking open the relief louvres (these allow only outward flow from the reactor buildings) at the duct entrance (Figure 5) from each reactor building. This enables the reactor buildings and relief duct volumes to be capable of containing a large LOCA, with the vacuum building isolated. It is felt, however, that in the event of a large loss of coolant, total plant shutdown would result. Statistically, the use of vacuum containment is expected to be utilized less than once every 3,000 reactor years so that the economic penalty of a total plant shutdown is considered small.

Another disadvantage of this system is the fact that in order to maintain the pressure relief valves (PRV's) people must enter the relief duct (Figure 5) with the vacuum building in the poised state and the units operating. The relief duct is normally held at the same pressure as the reactor buildings.

Typical vacuum containment system equipment is shown in more detail in Figure 6 (for Pickering). The pressure relief system consists of relief louvres, a duct interconnecting the reactor units pressure relief valves (12 at PGS, 16 at BGS) which isolate the reactor building atmospheres from that of the vacuum building during normal operation and vacuum ducts connecting the vacuum building to the relief duct.

During normal station operation, the vacuum building pressure is about 7 kPa(a) and the reactor buildings at about 0.25 kPa below atmospheric pressure. During accident conditions the pressure in the relief duct rises to 3.5 kPa(g) at which pressure the relief valves lift, allowing the steam/air mixture to be pulled into the vacuum building. Pressure in the vacuum building rises (remaining below atmospheric) and at 40 kPa(a) dousing via spray headers begins from water in a large storage tank in the vacuum building. By maintaining a vacuum in vacuum chambers on top of the roof, dousing by syphoning action via the sprays is maintained, condensing the steam and cooling the air until the pressure stabilizes and the vacuum building can be isolated for clean-up and restoration.

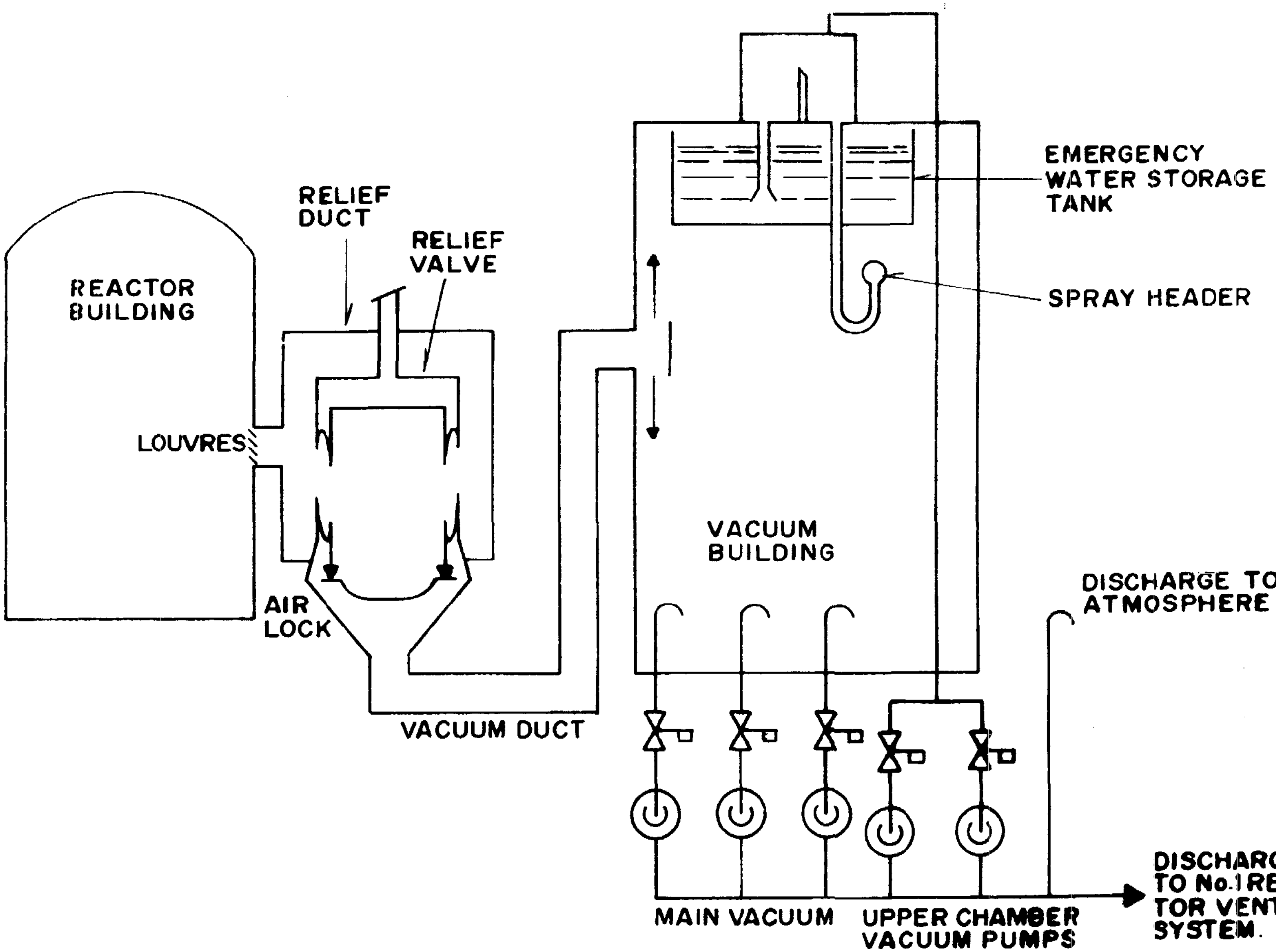


FIGURE 6

PICKERING G.S.

VACUUM CONTAINMENT SYSTEM

ASSIGNMENTS

1. Explain physically why the overpressure pulse following a LOCA lasts longer in a single unit pressure suppression containment system than in a vacuum containment system.

2. What are the advantages and disadvantages of

   (a) multi-unit vacuum containment systems

   compared to

   (b) single unit pressure suppression systems?

3. Describe the operation of a vacuum containment system following a rupture in the HT system under operating conditions.

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