General Electric Advanced Technology Manual

Chapter 6.5

Primary Containments

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

6.5 PRIMARY CONTAINMENTS

Learning Objectives:

1. State the purpose of the primary containment system.

2. Explain the multibarrier, pressure suppression concept as applied to each containment package.

3. Explain the response of the primary containments to a major LOCA.

4. Explain how post LOCA hydrogen gas evolution is controlled for each containment package.

6.5.1 Introduction

The primary containment package provided for a particular product line is dependent on the vintage of the plant and the cost-benefit analysis at the time. During the evolution of the Boiling Water Reactor, three major types of containments were built. The major containment designs are the Mark I, Mark II, and Mark III. Unlike the Mark III, that consists of a primary containment and a drywell, the Mark I and Mark II designs consist of a drywell and wetwell (suppression chamber). All three primary containment designs use the principle of pressure suppression for loss of coolant accidents. For comparison of containments see Table 6.5-1.

Each of the containment designs performs the same functions:

- Condenses steam and contains fission products released from a LOCA so that the offsite radiation doses specified in 10 CFR 100 are not exceeded.

- Provides a heat sink for certain safety related equipment.

- Provides a source of water for emergency core cooling systems and the Reactor Core Isolation Cooling System.

6.5.2 Mark I Containment

The Mark I containment design consists of several major components, many of which can be seen in Figure 6.5-1. These major components include the drywell, which surrounds the reactor vessel and recirculation loops; a suppression chamber, which stores a large body of water (the suppression pool); and an interconnecting vent network between the drywell and the suppression chamber. Additionally, there are numerous auxiliary systems associated with the primary containment that are required to meet its intended function.

6.5.2.1 Component Description

The major components of the primary containment system are discussed in the paragraphs that follow.

Drywell

The purposes of the drywell are to contain the steam released from a loss of coolant accident (LOCA) and direct it to the suppression chamber, and to prevent radioactive materials from passing through its portion of the primary containment boundary.

The drywell is a steel pressure vessel with a spherical lower portion and cylindrical upper portion. The top head closure is made with a double tongue and groove seal which permits periodic checks for tightness without pressurizing the entire vessel. Bolts secure the drywell head to the cylindrical section during conditions that require primary containment integrity. The drywell is enclosed by reinforced concrete for shielding and for additional resistance to deformation and buckling over areas where the concrete backs up the steel shell. Above the foundation, the drywell is separated from the reinforced concrete by a gap of approximately two inches for thermal expansion. Shielding over the top of the drywell is provided by removable, segmented, reinforced concrete shield plugs. In addition to the drywell head, one double door personnel air lock and two bolted equipment hatches are provided for access to the drywell.

Suppression Chamber

The suppression chamber consists of a steel pressure vessel with a toroidal shape (sometimes referred to as a torus) and a large body of water inside the suppression chamber (referred to as the suppression pool). The purposes of the suppression chamber are to condense steam released from a LOCA and to prevent radioactive materials from passing through this portion of the primary containment boundary.

The purposes of the suppression pool are as follows: to serve as a heat sink for LOCA blowdown steam; to serve as a heat sink for safety/relief valve discharge steam and to serve as a heat sink for high pressure coolant injection (HPCI) system and reactor core isolation cooling (RCIC) system turbine exhaust steam; to provide a source of water for the low pressure coolant injection (LPCI) mode of the residual heat removal (RHR) system, core spray system, HPCI system, and RCIC system,
The suppression chamber is located radially outward and downward from the drywell and is held on supports which transmit vertical and seismic loading to the reinforced foundation slab of the reactor building.

Access to the suppression chamber is provided through two manways with double gasket bolted covers. These access ports (manways) are bolted closed when primary containment integrity is required and can be opened only when primary coolant temperature is below 212°F and the pressure suppression system is not required to be operational.

Interconnecting Vent System

The interconnecting vent network is provided between the drywell and suppression chamber to channel the steam and water mixture from a LOCA, to the suppression pool and allow noncondensible gases to be vented back to the drywell. Eight large vent pipes (81" in diameter) extend radially outward and downward from the drywell into the suppression chamber. Inside the suppression chamber the vent pipes exhaust into a toroidal vent header which extends circumferentially all the way around the inside of the suppression chamber. Extending downward from the vent header are ninety six downcomer pipes which terminate about three feet below the suppression pool minimum water level. Jet deflectors are provided in the drywell at the entrance to each vent pipe to prevent possible damage to the vent pipes from jet forces which might accompany a line break in the drywell. The vent pipes are provided with expansion joints to accommodate differential motion between the drywell and suppression chamber.

Vacuum Relief System

There are two vacuum relief networks associated with preventing the primary containment from exceeding the design external pressure of 2 psi. The first vacuum relief network consists of a set of twelve self actuating swing check valves. These suppression chamber-to-drywell vacuum relief valves vent noncondensible gases from the suppression chamber to the drywell whenever suppression chamber pressure exceeds drywell pressure by 0.5 psid. The second vacuum relief network consists of a set of two vacuum relief lines from the reactor building (secondary containment) to the suppression chamber. Each line contains a self actuated check valve and an air operated butterfly type vacuum breaker in series. These reactor building to suppression chamber vacuum relief lines vent air from the reactor building to the suppression chamber whenever reactor building pressure exceeds suppression chamber pressure by 0.5 psid.

The suppression chamber-to-drywell vacuum breakers are remotely tested by using air cylinder actuators. Testing of the suppression chamber to reactor building vacuum breakers is accomplished by testing the equipment which automatically opens the air operated butterfly valves and manually exercising the check valves.

Drywell Cooling System

During normal plant operation there is a closed atmosphere within the drywell and the suppression chamber. Since the reactor vessel is located within the drywell, heat must be continuously removed from the drywell atmosphere. Drywell temperature is maintained between <135°F by operating drywell cooling units. Each cooling unit consists of a motor driven fan which blows the existing drywell atmosphere (either nitrogen gas or air) past a heat exchanger which is cooled by the reactor building closed cooling water (RBCCW) system or an equivalent system.

Primary Containment Ventilation System

The purpose of the primary containment ventilation system is to allow for influent air to be brought into the drywell and suppression chamber and for effluent atmosphere to be discharged from the drywell and suppression chamber. This system uses connections to the reactor building heating, ventilation, and air conditioning (HVAC) system for influent air. Connections to the reactor building via the primary containment purge system and to the standby gas treatment system (SGTS) are used for effluent atmosphere. The reactor building HVAC system is used to supply filtered and temperature controlled outside air to the primary containment for air purge and ventilation purposes to allow for personnel access and occupancy during reactor shutdown and refueling operations. The purge exhaust air is either removed by the primary containment purge system and discharged to the atmosphere via the reactor building HVAC system exhaust fans or removed by the standby gas treatment system and discharged to the atmosphere via the plant stack. In either case the effluent is treated prior to release.

Containment Inerting System

The purpose of the containment inerting system is to create and maintain an inerted atmosphere of nitrogen gas inside the primary containment during normal plant power operation. It is necessary to inert the primary containment atmosphere with nitrogen gas in order to maintain the primary containment oxygen concentration less than 4%. Starting with an inerted atmosphere is important in preventing an explosive mixture of hydrogen and oxygen in the primary containment atmosphere following postulated loss of coolant accidents with postulated hydrogen generation.

The containment inerting system consists of a nitrogen (N2) purge supply and a nitrogen (N2) makeup supply. The N2 purge supply is used to initially create the inerted atmosphere in the primary containment. Nitrogen purge systems consist of a liquid nitrogen storage tank, a steam vaporizer (to convert liquid nitrogen to the gaseous state), and associated valving and piping to deliver nitrogen to the primary containment influent ventilation lines. Nitrogen gas is supplied to the primary containment through the purge supply at a rate of 3000-4500 scfm while primary containment atmosphere is discharged to the reactor building HVAC system exhaust ventilation duct or to the standby gas treatment system. This process continues until primary containment oxygen concentration is less than 4%, which takes approximately four hours and requires three to five containment atmosphere volumetric changes.

After the inerted atmosphere has been created, the nitrogen makeup supply is used to continue to supply nitrogen gas as required by temperature changes and leakage. The primary containment is held at a slight positive pressure by the makeup supply and uses the same liquid nitrogen storage tank, its own vaporizer, and valving and piping to deliver nitrogen gas at a rate of <60 scfh to the primary containment.

Containment Atmosphere Dilution System

The purpose of the containment atmosphere dilution (CAD) system is to control the concentration of combustible gases in the primary containment subsequent to a loss of coolant accident with postulated high hydrogen generation rates. The CAD system is capable of supplying nitrogen gas at a rate sufficient to maintain the oxygen concentrations of both the drywell and suppression chamber atmospheres below 5% by volume based on the hydrogen generation rate associated with a 5% metal-water reaction.

The CAD system nitrogen supply facilities shown in some detail in figure 6.5-2, include two separate trains, each of which is capable of supplying nitrogen through separate piping systems to the drywell and suppression chamber. Each train includes a liquid nitrogen supply tank, an ambient vaporizer, an electric heater, a manifold with branches to the primary containment; and pressure, flow, and temperature controls. The nitrogen storage tanks have a nominal capacity of 3000 gallons each which is adequate for the first seven days of CAD system operation. The nitrogen vaporizers use ambient atmosphere as the heat source. Electric heaters are provided for use during cold weather to warm the gas.

Following a LOCA, records are kept of hydrogen and oxygen concentrations and pressures in the drywell and suppression chamber. The CAD system is then operated manually to keep the oxygen concentration <5% or the hydrogen concentration <4% in each volume. Additions are made separately to the drywell and suppression chamber. Manual initiation of the CAD system is calculated to be required about 10 days following postulated design basis LOCA.

When the CAD system is adding nitrogen to the drywell and/or suppression chamber, pressure will increase. Before drywell pressure reaches 30 psig, drywell venting via the standby gas treatment system will be started. Gas releases will be performed periodically and independently from the drywell and suppression chamber.

Releases will be made during periods of the most favorable meteorological conditions at a rate of approximately 100 scfm until the desired volume has been released. Releases will continue over time until primary containment pressure has been reduced to atmospheric. Additions and releases will be conducted at different times.

6.5.2.2 Containment Response to a LOCA

When the postulated line break occurs, the drywell is immediately pressurized. As drywell pressure increases, drywell atmosphere (primarily nitrogen gas) and steam are blown down through the radial vents to the vent header and into the suppression pool via the downcomers. The steam condenses in the suppression pool which suppresses the peak pressure realized in the drywell. Drywell pressure peaks at 49.6 psig at about 10 seconds following the line break. Noncondensible gases discharged into the suppression pool end up in the free air volume of the suppression chamber which accounts for the suppression chamber pressure increase. As LOCA steam is condensed in the suppression pool, drywell pressure decreases and stabilizes 27 psig while suppression pool temperature reaches 135°F. Drywell pressure decreases to the point that suppression chamber pressure exceeds it by 0.5 psid. This causes the suppression chamber-drywell vacuum breakers to open and vent noncondensible gases back into the drywell to equalize the drywell and suppression chamber pressures.

Low pressure emergency core cooling systems (ECCS) begin pumping water into the reactor vessel, removing decay and stored heat from the core. Water injected into the reactor vessel then transports core heat out of the reactor vessel via the broken recirculation loop. The hot water collects on the drywell floor and then flows into the suppression chamber via the vent pipes, vent header, and downcomer pipes. Thus a closed loop is formed with low pressure ECCS pumps (core spray system and RHR system LPCI mode) pumping water from the suppression pool to the reactor vessel. The water then returns to the suppression pool and the process is repeated.

At about 600 seconds it is assumed that the RHR system would be switched from the LPCI mode to suppression pool cooling. In this mode suppression pool heat is removed via the RHR heat exchangers causing primary containment temperature and pressure to decrease. If necessary, the containment spray mode of the RHR system can be initiated to spray cooled suppression pool water into the drywell and/or suppression chamber atmospheres to control primary containment pressure.

6.5.3 Mark II Containment

The Mark II primary containment (figures 6.5-3 and 6.5-4) consists of a steel dome head and either a post-tensioned concrete wall or reinforced concrete wall standing on a base mat of reinforced concrete. The inner surface of the containment is lined with steel plate which acts as a leak tight membrane. The containment wall also serves as a support for the floor slabs of the reactor building and for the refueling pools. The floor slabs are resting on corbels that are formed as part of the containment wall. The refueling pools are integrally connected to, and supported by the concrete containment wall.

The suppression system is the over-and-under configuration. The drywell, in the form of a truncated cone, is located directly above the suppression pool. The suppression chamber is

cylindrical and separated from the drywell by a reinforced concrete slab. The drywell is topped by an elliptical steel dome called the drywell head. The drywell inerted atmosphere is vented into the suppression chamber through a series of downcomer pipes penetrating and supported by the drywell floor.
In order to prevent flooding of the drywell during refueling, a bellows type seal is used to seal the space between the reactor vessel and the drywell. The bellows permits free relative movement and offers some restraint to relative lateral displacement of the RPV and the primary containment vessel.

6.5.4 Mark III Containment

BWR/6 product lines use the Mark III containment concept. The Mark III containment is a multibarrier, pressure suppression style containment. The containment structure is similar to a standard dry containment and can be designed as either a free standing steel containment surrounded by a concrete shield building or as a concrete pressure vessel with a liner. The former design is referred to as the reference design while the latter is the alternate. Discussion in this section is limited to the reference design.

The primary containment consists of several major components, many of which can be seen in figure 6.5-5. The drywell is a cylindrical, reinforced concrete structure with a removable steel head and encloses the reactor vessel. It is designed to withstand and confine the steam generated during a pipe rupture inside containment and channel this steam into the suppression pool via the weir wall and horizontal vents. The suppression pool contains a large volume of water to act as a heat sink and water source for ECCSs. A leak tight cylindrical steel containment vessel surrounds the drywell and the suppression pool to prevent gaseous and particulate fission products from escaping to the environment.

6.5.4.1 Component Description

The major components of the primary containment system are discussed in the paragraphs that follow.

Drywell

The drywell is a cylindrical reinforced concrete structure with a removable vessel head to allow vertical access to the reactor vessel for refueling or maintenance. The drywell is designed for an internal pressure of 30 psig, an external pressure of 21 psig, and an internal temperature of 330°F. However, a high degree of leak tightness is not a requirement since the drywell is not a fission product barrier.

Large diameter horizontal vent openings penetrate the lower section of the drywell cylindrical wall to channel steam from a LOCA into the suppression pool.

The main function of the drywell is to contain the steam released from a LOCA and direct it into the suppression pool. Other functions of the drywell include:

- provide shielding to reduce containment radiation levels to allow normal access.
- provide structural support for the upper pool.
- provide support structure for work platforms, monorails, and pipe supports.

Horizontal Vents and Weir Wall

The weir wall forms the inner boundary of the suppression pool, and is located inside the drywell. It is constructed of reinforced concrete approximately two feet thick and lined with a steel plate on the suppression pool side.

Since the weir wall forms the inside wall of the suppression pool, it contains the pool and allows channeling the steam released by a LOCA into the suppression pool for condensation. The weir wall height is 25 feet and allows a minimum freeboard of 5 feet 8 inches. This freeboard is sufficient height to prevent the suppression pool from overflowing into the drywell.

The Mark III arrangement uses horizontal vents to conduct the steam from the drywell to the suppression pool following a LOCA. Figure 6.5-6 shows an enlarged horizontal and vertical section of vents. In the vertical section, the drywell wall is penetrated by a series of 27.5 inch diameter horizontal vent pipes. There are 3 rows of these horizontal pipes at levels of 7.5, 12 and 16.5 feet below the surface of the suppression pool. The total pool depth is approximately 20 feet. The horizontal section is a partial view of the 40 column of vents, vent annulus, and weir wall.

Any buildup of drywell pressure forces the water down in the annulus. The higher the pressure in the drywell, the greater the depression and the number of vents that will be uncovered.

Containment

The containment is a free standing cylindrical steel pressure vessel that surrounds the drywell and suppression pool to form the primary leak tight barrier to limit fission product leakage during a LOCA. By design the containment will not leak more than 0.1% of the containment volume in 24 hours at a pressure of 15 psig.

Among the postulated LOCAs, some accidents may require flooding the containment to remove fuel from the reactor and effect repairs. Although it is anticipated that for most accidents, defueling of the reactor will be accomplished by normal procedures and equipment, as a contingency to cover undefined damage resulting from a LOCA, the containment can be flooded to a level 6 feet 10 inches above the top of the active fuel in the core.

Upper Pool

The containment upper pool walls are above the drywell and within the containment column. The pool is completely lined with stainless steel plates and consists of five regions:

- moisture separator storage
- reactor well
- steam dryer storage
- temporary fuel storage
- fuel transfer region

The upper pool provides radiation shielding when the reactor is operating, storage for refueling operation, and a source of water makeup for the suppression pool following a LOCA.

Combustible Gas Control

To ensure containment integrity is not endangered because of the generation of combustible gases following a postulated LOCA, the containment is protected by a collection of systems called the containment combustible gas control system (CCGC system).

The CCGC system, figure 6.5-7, prevents hydrogen concentration in the primary containment from exceeding the flammability limit of 4% (by volume). The system is capable of mixing the atmosphere inside the drywell with that inside containment following a LOCA. When the drywell hydrogen concentration begins to increase, the drywell mixing compressors are started manually by the control room operator. Air from the containment is pumped into the drywell increasing drywell pressure. The increase in drywell pressure depresses the annulus water uncovering vents and allowing the drywell atmosphere to mix with the containment.

While drywell mixing continues following a LOCA, hydrogen continues to be produced. Eventually, the 4% limit is approached in the containment, requiring the hydrogen recombiners and hydrogen ignition system to be manually placed in operation. The recombiners are located in the containment upper region. Air flow through the recombiner is designed to process 100 cfm of containment air, heating it to 1150°F. The heated air leaving the heater section is mixed with containment atmosphere to limit the outlet temperature to approximately 50°F above ambient.

The hydrogen ignition system consists of hydrogen ignitors distributed throughout the drywell and containment. The ignitors burn the hydrogen as its evolved to maintain the concentration below detonable limits.

A small line, connecting the drywell with the shield building annulus, is used during reactor startup and heatup. Drywell pressure is vented to the annulus through the bleedoff and backup purge line. This venting can support plant heatup at the design rate of 100 °F/hr. If hydrogen recombiners are not available subsequent to a LOCA, the drywell bleedoff valves may be opened for backup purging. This flowpath allows about 100 cfm of air from the drywell to enter the shield building annulus where it is removed and then later processed by the standby gas treatment system.

6.5.5 Summary

The primary containment package provided for a particular product line is dependent on the vintage of the plant and the cost-benefit analysis at the time. During the evolution of the boiling water reactor, three major types of containments were built. The major containment designs are the Mark I, Mark II, and Mark III. Unlike the Mark III, that consists of a primary containment and a drywell, the Mark I and Mark II designs consist of a drywell and wetwell (suppression chamber). All three primary containment designs use the principle of pressure suppression for loss of coolant accidents. For comparison of containments see table 6.5-1.

Table 6.5-1 Containment Comparison Chart

	Mark I (BFNP)	Mark II (LaSalle)	Mark III (Perry)
Drywell Material	Steel	Concrete	Concrete
Drywell Thickness (ft)	.17	6	6
Drywell Upper Diameter (ft)	39	31	73
Drywell Lower Diameter (ft)	67	73	73
Drywell Height (ft)	115	91	89
Drywell Free Air Volume (ft^3)	159,000	209,300	277,685
Drywell Design Internal Pressure (psig)	56	45	30
Drywell Design External Pressure (psig)	2	5	21
Drywell Deck Design d/p (psid)	N/A	25	N/A
Drywell Design Temperature (^oF)	281	340	330
Drywell max. Calculated LOCA Pressure (psig)	49.6	34	22.1
Shield above RPV Head	Concrete	Concrete	Water
Suppression Chamber (or Containment) Thickness (ft)	.17	4	.15
Suppression Chamber (or Containment) Steel Liner Thickness	N/A	.25	N/A
Suppression Chamber (or Containment) Diameter ft)	111	87	120
Suppression Chamber (or Containment) Height (ft)	31	67	183
Suppression Chamber (or Containment) Free Air Volume (ft^3)	119,000	164,500	1,141,014
Suppression Pool Volume in Drywell (ft^3)	N/A	N/A	11,215
Total Suppression Pool Volume (ft^3)	135,000	124,000	129,550
Upper Pool Makeup to Suppression Pool (ft^3)	N/A	N/A	32,830
Suppression Chamber (or Containment) Design Internal Pressure (psig)	56	45	15
Suppression Chamber (or Containment) Design External Pressure (psig)	2	5	0.8
Suppression Chamber (or Containment) Design Temperature	281	275	185
Suppression Chamber (or Containment) max. Calculated	27	28	11.31
Suppression Chamber (or Containment) design Leak Rate (% of vol/Day)	.5	.5	.2
Number of Drywell to Suppression Chamber (or Containment) vents	8	98	120
Total Vent Area (ft^3)	286	308	512
Drywell Atmosphere	N_2	N_2	Air

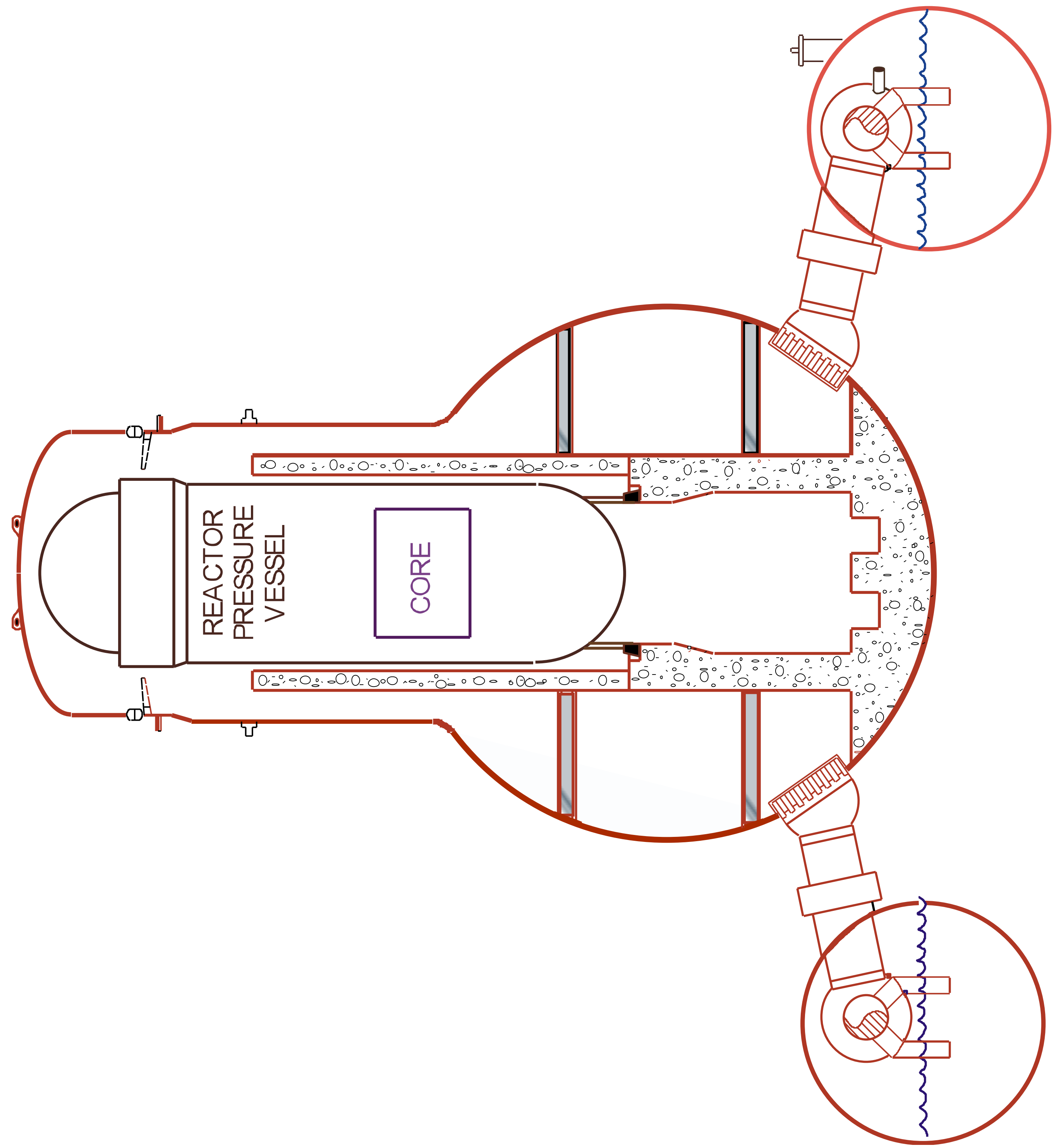

Figure 6.5-1 Mark I Containment

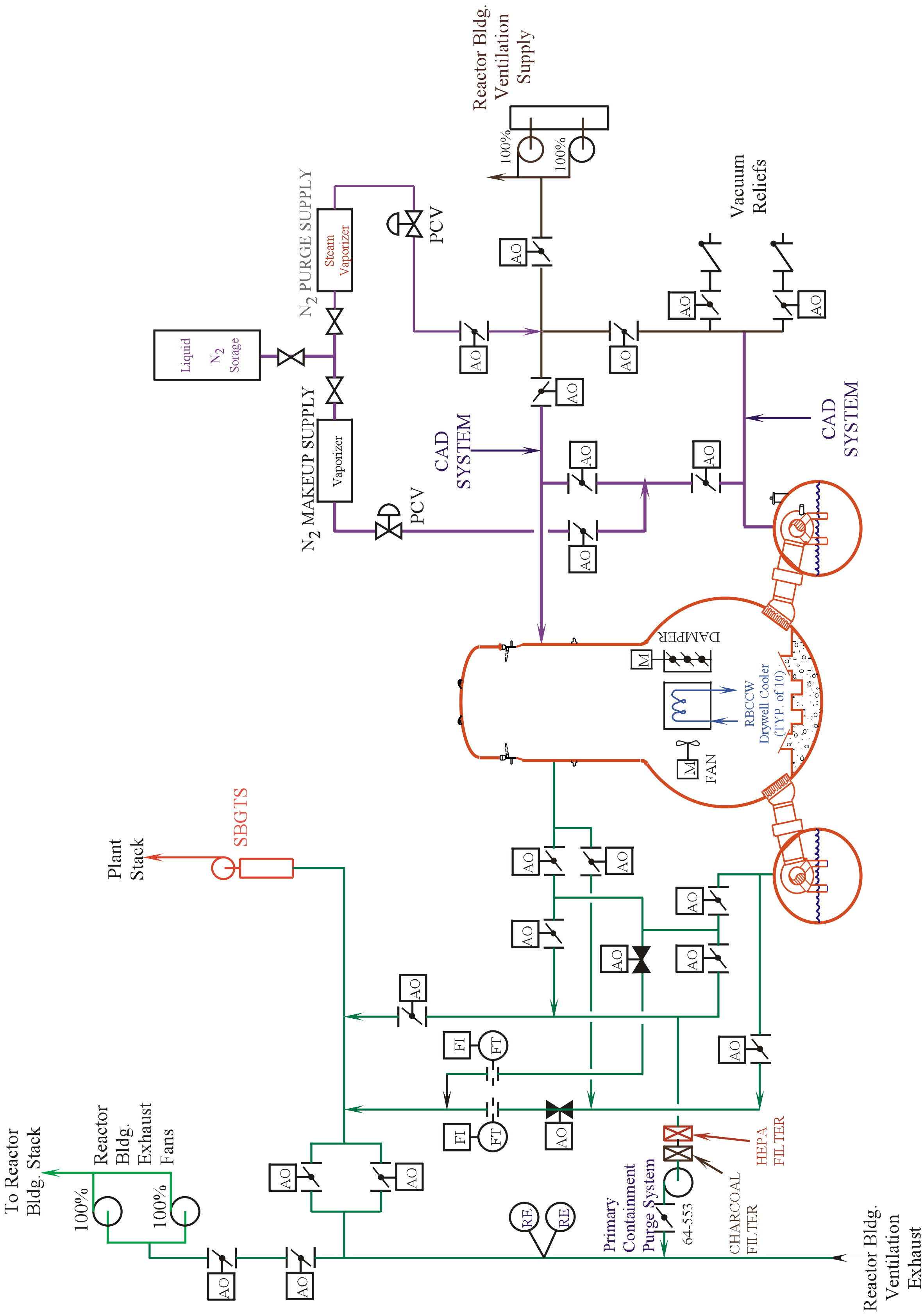

Figure 6.5-2 Mark I Containment Combustible Gas Control

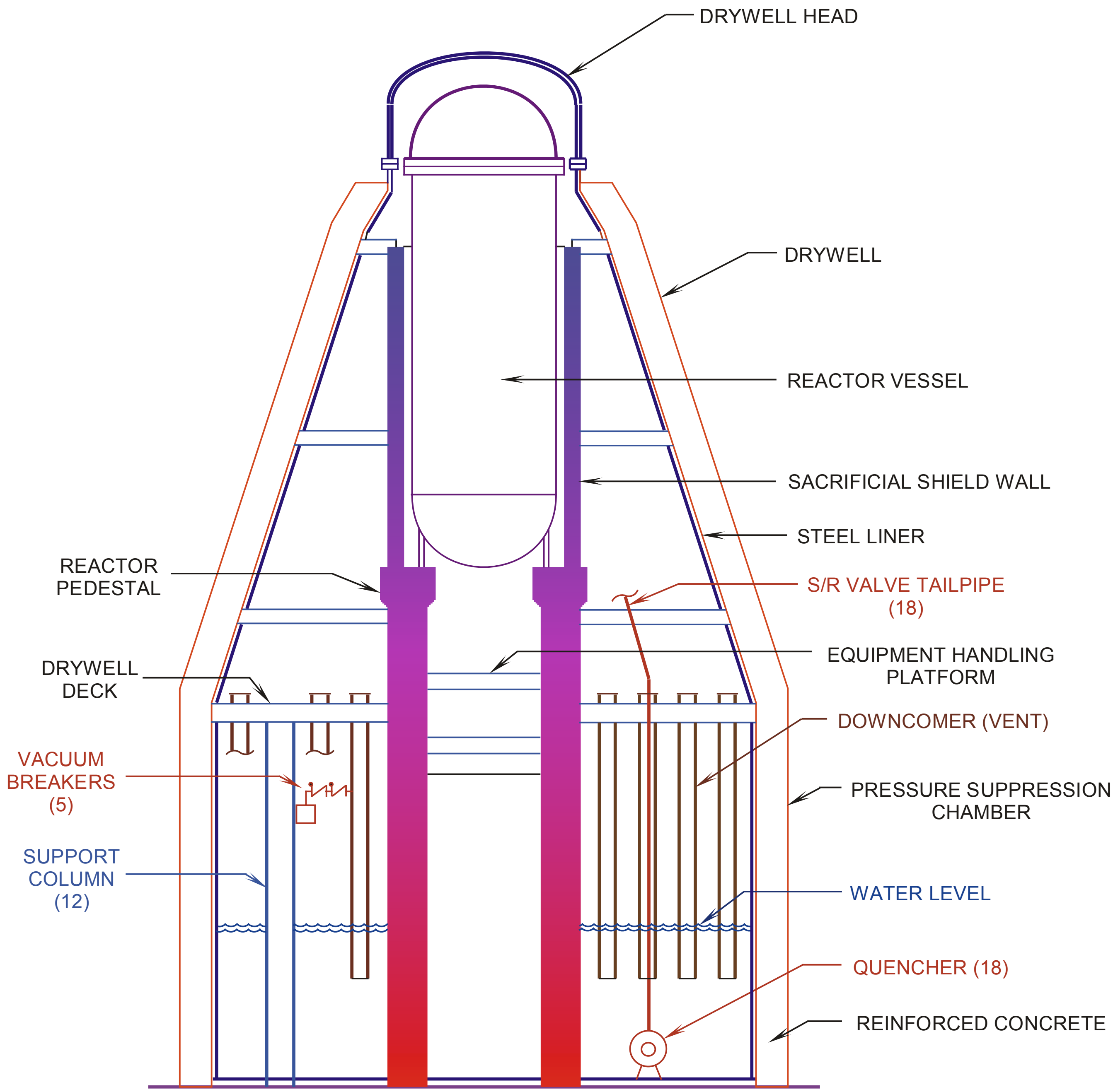

Figure 6.5-3 Mark II Containment

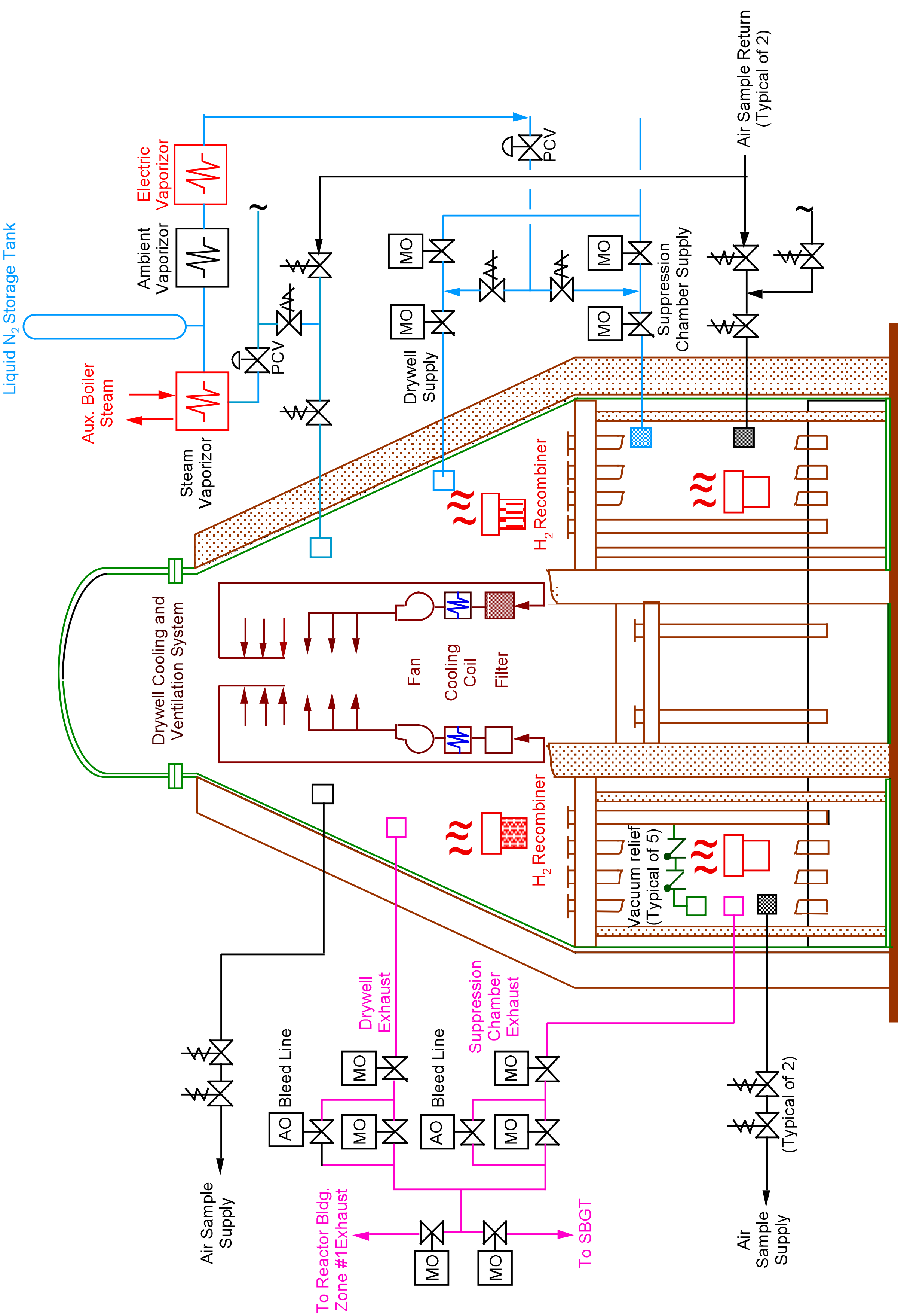

Figure 6.5-4 MARK II Containment Combustible Gas Control

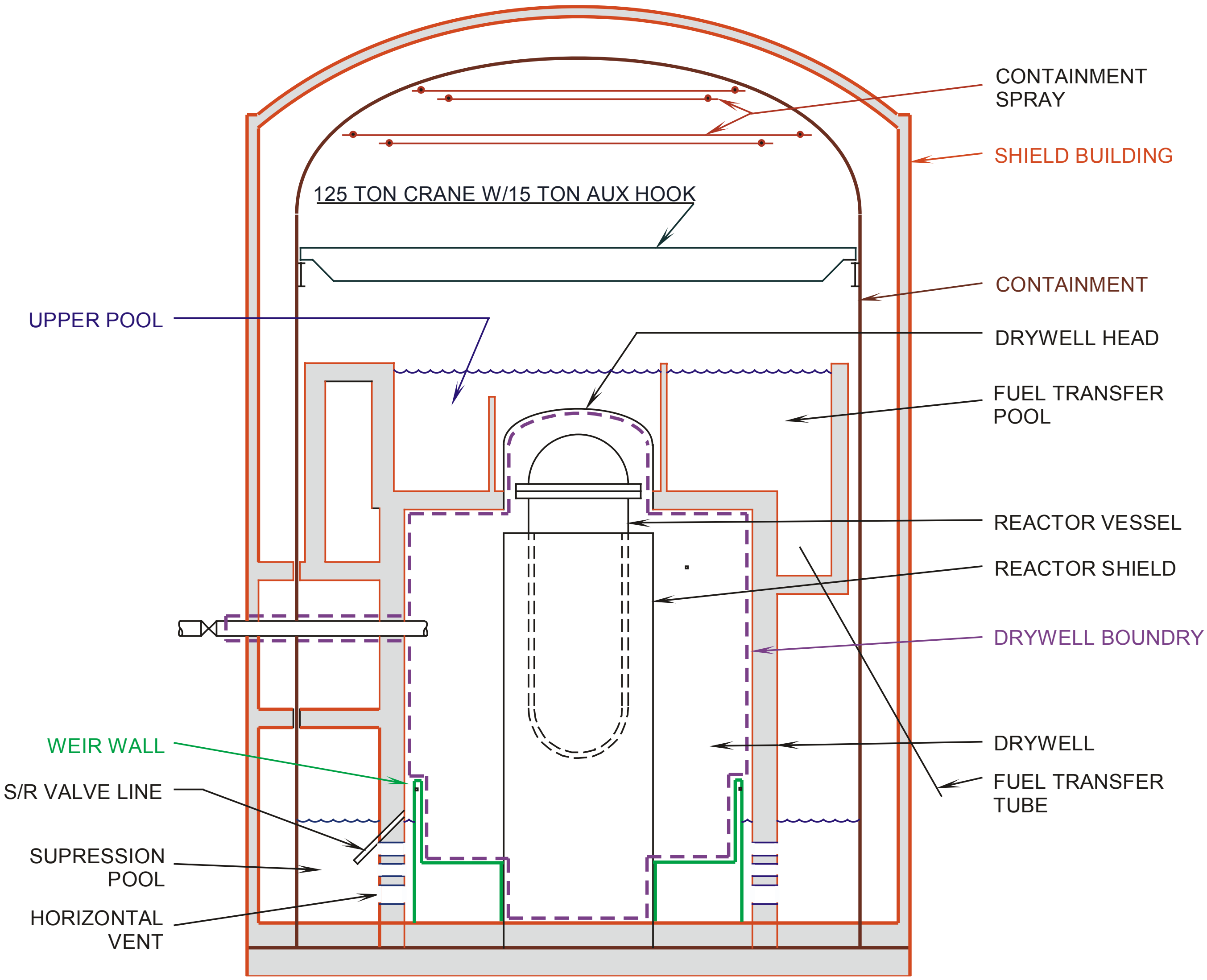

Figure 6.5-5 Mark III Containment

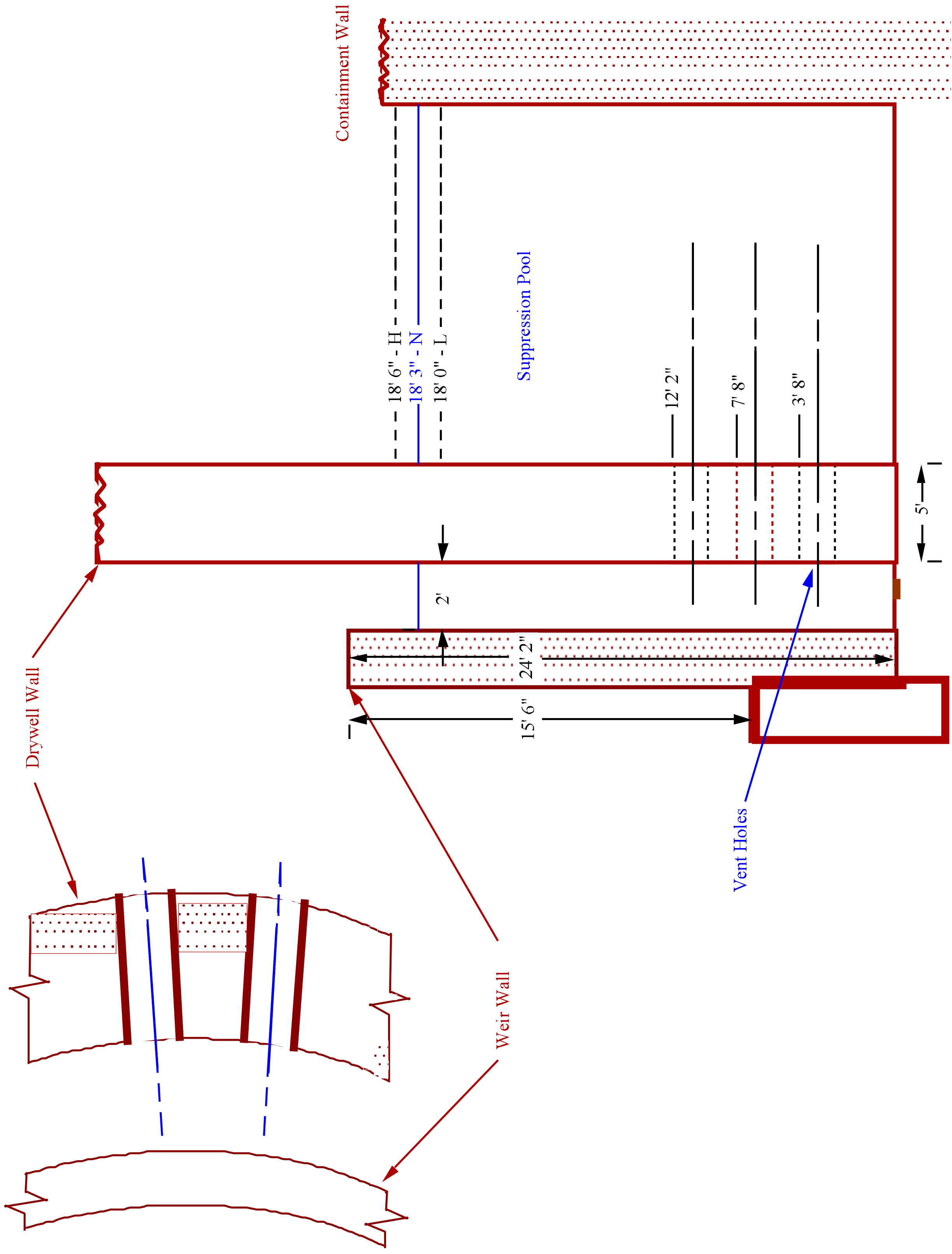

Figure 6.5-6 Mark III Containment Vent Arrangement

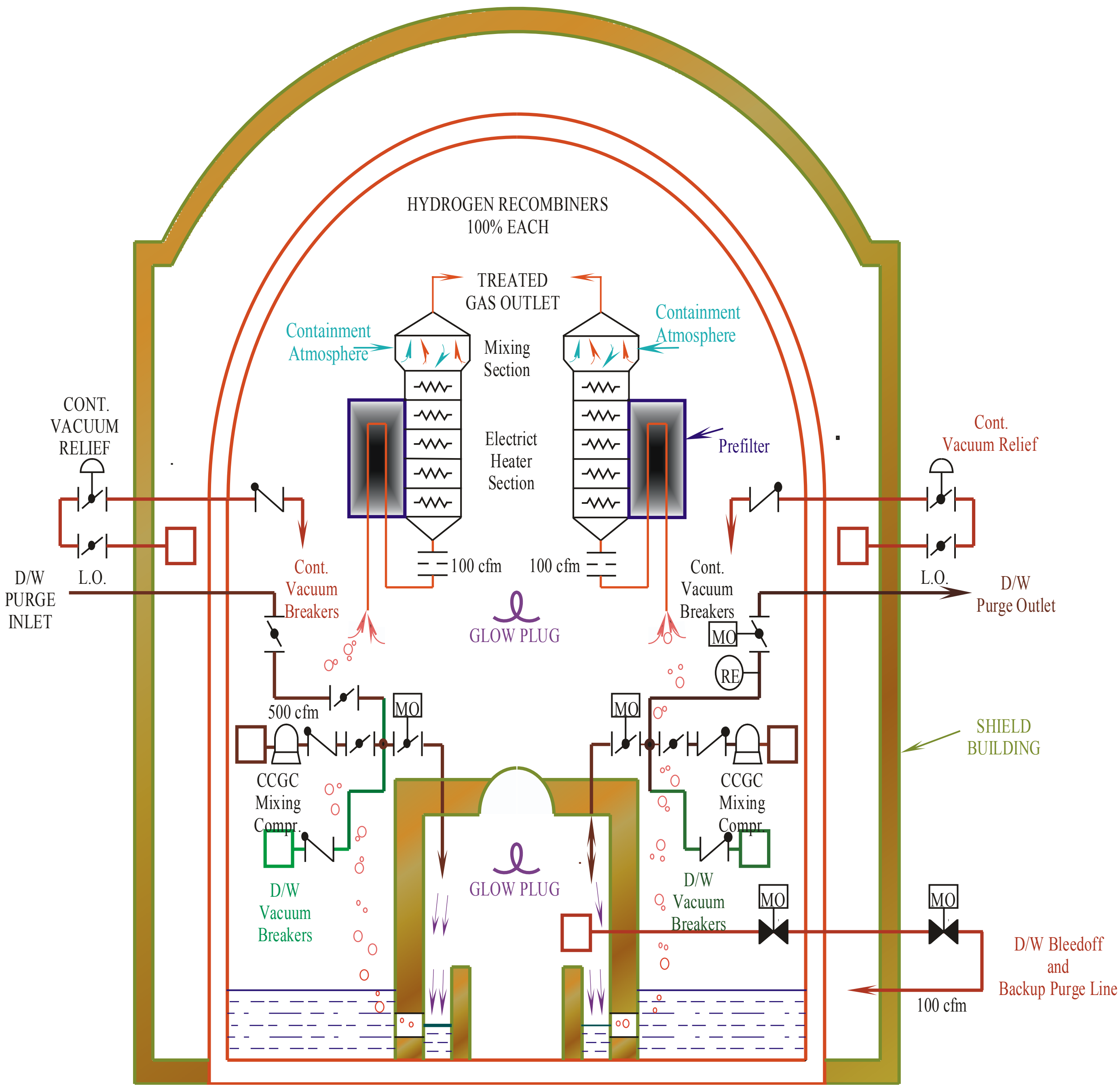

Figure 6.5-7 Mark III Containment Combustible Gas Control