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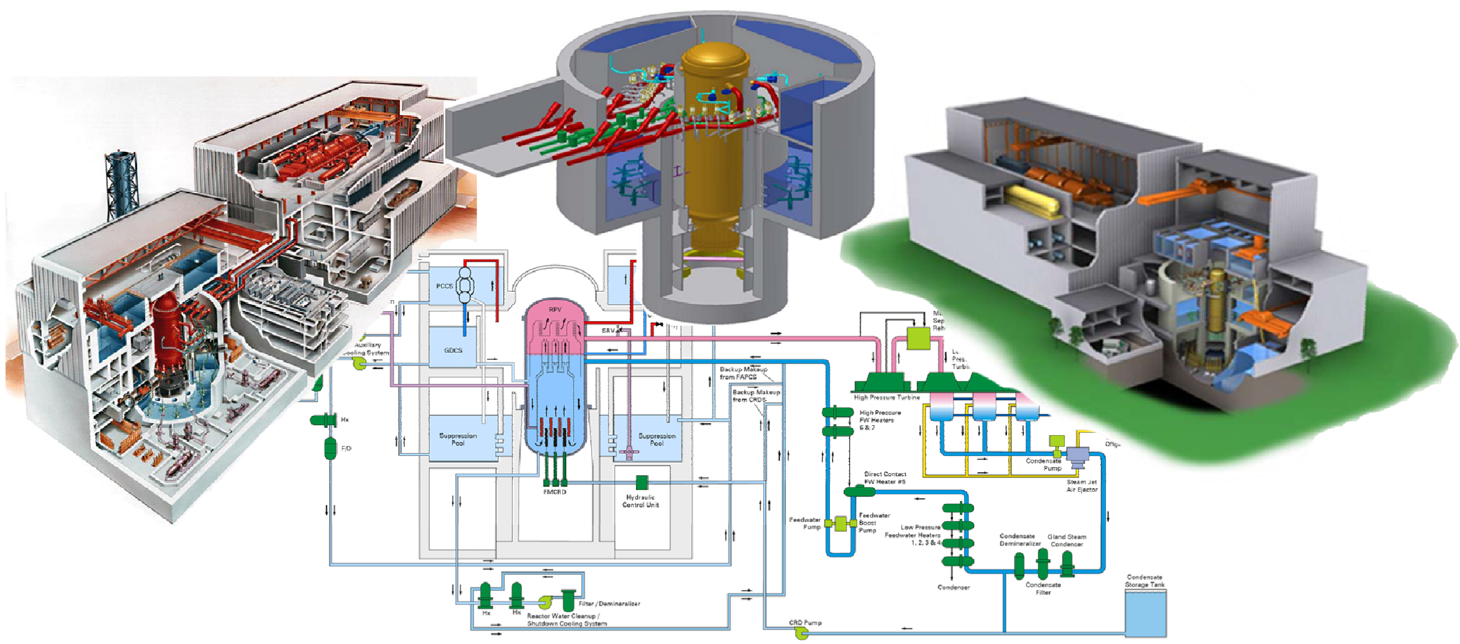

Part II
Introduction to Reactor Technology

Chapter 9.0, Containment Systems

Human Resources
Training & Development

UNITED STATES

NUCLEAR REGULATORY COMMISSION

HUMAN RESOURCES TRAINING & DEVELOPMENT

Introduction to Reactor Technology

This manual is a text and reference document for the Introduction to Reactor Technology for the media briefing. It should be used by students as a study guide during attendance at this course. This manual was compiled by staff members from the Human Resources Training & Development in the Office of Human Resources.

The information in this manual was compiled for NRC personnel in support of internal training and qualification programs. No assumptions should be made as to its applicability for any other purpose. Information or statements contained in this manual should not be interpreted as setting official policy. The data provided are not necessarily specific to any particular nuclear power plant, but can be considered to be representative of the vendor design.
The Introduction to Reactor Technology – BWR briefing manual outlines the differences between the Boiling Water Reactors (BWR), Advanced Boiling Water Reactor (ABWR), and Economic Simplified Boiling Water Reactor (ESBWR). The course is broken down into discussions on design features, facility and plant layout, containment systems, nuclear steam supply systems, control and instrumentation, safety systems, balance of plant systems, normal, abnormal, and emergency operations.
The content of this course was based on the content provided in the following references:

- General Electric Systems Manual
- Introduction to ABWR Manual
- Introduction to ESBWR Course Manual
- Economic Simplified Boiling Water Reactor Plant General Description; June 2006, General Electric Company
- NUREG-1503, Final Safety Evaluation Report Related to the Certification of the Advanced Boiling Water Reactor Design and Appendices, U.S. Nuclear Regulatory Commission Office of Nuclear Reactor Regulation, July 1994
- ABWR, Advanced Boiling Water Reactor Plant General Description, “First of the Next Generation,” GE Nuclear Energy, June 2000
- Nuclear News, World List of Nuclear Power Plants, American Nuclear Society, March 2007
- J. Alan Beard & L.E. Fennern, General Electric presentation to DOE et.al, April 13th 2007, Germantown Md.

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The information contained in this chapter pertains to current operational reactor designs. Advanced reactor designs are provided in separate chapters.

9.0 CONTAINMENT SYSTEMS

Containment systems provide a multi-barrier pressure suppression type containment. The fuel, fuel cladding and reactor coolant system form initial barriers to the release of fission products. This chapter describes a containment system which encloses the Reactor Coolant system and is composed of a Primary Containment (the pressure suppression system), a Secondary Containment (the reactor building), a Standby Gas Treatment system and a Primary Containment Isolation system.

9.0.1 Primary Containment System

The Primary Containment consists of a drywell which encloses the reactor vessel and recirculation system, a pressure suppression chamber which stores a large volume of water, a connecting vent system between the drywell and the suppression chamber, isolation valves and containment atmosphere control systems.

9.0.2 Secondary Containment System

The Secondary Containment consists of the reactor building, which serves as the secondary containment membrane; and low leakage dampers and valves used to isolate the secondary containment. The reactor building serves as a dilution and holdup volume for fission products which may leak from the primary containment following an accident.

The reactor building houses most of the reactor auxiliary and support systems including the Emergency Core Cooling systems, the Reactor Water Cleanup system, the Control Rod Drive system and the refueling and support facilities.

9.0.3 Standby Gas Treatment System

The Standby Gas Treatment system processes exhaust air from the secondary containment under accident conditions to limit radiation dose rates to less than 10 CFR 100 limits. The Standby Gas Treatment system is also used to purge the primary containment and leak test the secondary containment.

9.0.4 Primary Containment Isolation System

The Primary Containment Isolation system is used to automatically isolate the primary and secondary containments and reactor vessel during abnormal or accident conditions. This is done to prevent the release of radioactive materials in excess of specified limits.

9.1 PRIMARY CONTAINMENTS

9.1.1 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 9.1-1.

Each of the containment designs performs the same functions:

- condenses steam and contains fission products released from a Loss Of Coolant Accident (LOCA) so that the off site radiation doses specified in 10 CFR 100 are not exceeded,
- provides a heat sink for certain safety related equipment, and
- provides a source of water for emergency core cooling systems and the Reactor Core Isolation Cooling (RCIC) system.

9.1.2 Mark I Containment

The Mark I containment design consists of several major components, many of which can be seen in Figure 9.1-1. 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.

9.1.2.1 Component Description

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

9.1.2.1.1 Drywell

The purposes of the drywell are to contain the steam released from a 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.

9.1.2.1.2 Suppression Chamber

The suppression chamber consists of a steel pressure vessel with a toroidal shape (sometimes referred to as 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, for High Pressure Coolant Injection (HPCI) system and RCIC system turbine exhaust steam, and
- 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^{o}F and the pressure suppression system is not required to be operational.

9.1.2.1.3 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 noncondensable 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.

9.1.2.1.4 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 noncondensable 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.

9.1.2.1.5 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^{o}F and 150^{o}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 Loop Cooling Water (RBCCW) system or an equivalent system.

9.1.2.1.6 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 (SBGT) system 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 SBGT and discharged to the atmosphere via the plant stack. In either case, the effluent is treated prior to release.

9.1.2.1.7 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 (N_2) purge supply and a N_2 makeup supply. The N_2 purge supply is used to initially create the inerted atmosphere in the primary containment. N_2 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 SBGT 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 N_2 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.

9.1.2.1.8 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 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 SBGT 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.

9.1.2.2 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 at 27 psig while suppression pool temperature reaches 135^{o}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 noncondensable 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 LPCI mode of RHR) 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.

9.1.3 Mark II Containment

The Mark II primary containment (Figure 9.1-2) 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 a 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 refueling pools are integrally connected to, and supported by the concrete containment wall.

The suppression system is an 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.

9.1.4 Mark III Containment

BWR/6 product lines use the Mark III containment concept. The Mark III containment (Figure 9.1-3) is a multi-barrier, 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. 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 ECCS. 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.

9.1.4.1 Component Description

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

9.1.4.1.1 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^{o}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, and
- provide support structure for work platforms, monorails, and pipe supports.

9.1.4.1.2 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. 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.

9.1.4.1.3 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.

9.1.4.1.4 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, and
- 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.

9.1.4.1.5 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 (CCGC) system.

The CCGC system 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^{o}F. The heated air leaving the heater section is mixed with containment atmosphere to limit the outlet temperature to approximately 50^{o}F above ambient.

The hydrogen ignition system consists of hydrogen ignitors distributed throughout the drywell and containment. The ignitors burn the hydrogen as it's 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 flow path 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 SBGT system.

Table 9.1-1, 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 (^oF)	281	275	185
Suppression Chamber (or Containment) max. Calculated LOCA	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

9.2 SECONDARY CONTAINMENT SYSTEM

The purposes of the Secondary Containment are:

- to minimize the ground level release of airborne radioactive materials following an accident, and
- to serve as the primary containment during refueling operations.

The functional classification of the Secondary Containment system is that of a safety related system. Its regulatory classification is that of an Engineered Safety Feature (ESF) system.

9.2.1 System Description

The secondary containment (reactor building), shown in Figure 9.2-1, is a physical boundary which encloses the primary containment. The reactor building also houses the refueling and reactor servicing equipment, new and spent fuel storage facilities, Emergency Core Cooling systems, Reactor Water Cleanup system, Standby Liquid Control system, Control Rod Drive system, instrumentation for the Reactor Protection system and electrical components.

During normal operation the reactor building atmosphere is maintained at a 0.25 inch of water vacuum to assure any leakage would be inleakage. Outside air is brought in through isolation valves and filters by reactor building supply fans and then distributed to the various rooms within the reactor building. Reactor building exhaust fans take suction on the various rooms and discharge through isolation valves to an elevated release stack.

The isolation valves are actuated during abnormal conditions by the Primary Containment Isolation system (Section 9.4), to ensure containment of radioactive materials.

9.2.2 Component Description

The components which comprise the Secondary Containment system are discussed in the following paragraphs.

9.2.2.1 Reactor Building

The reactor building substructure consists of poured in place reinforced concrete which extends up to and including the refueling floor. The superstructure of the reactor building, above the refueling floor, is a structural steel frame.

The reinforced concrete exterior walls and the structural steel for the superstructure are designed for tornado considerations and missile protection. In addition, relief (blowout) panels are installed to prevent excessive internal reactor building pressure.

9.2.2.2 Air Locks and Penetrations

All entrances and exits to and from the reactor building are through double door personnel and equipment air locks. Each access door is equipped with weather strip type rubber construction seals and are electrically interlocked so that only one door, of a pair, may be open at a time.

Secondary containment piping penetrations are provided with a means for isolating the piping to prevent and/or minimize any release to the environment.

9.2.2.3 Ventilation

The Reactor building ventilation (Figure 9.2-2) system consists of is provided by equipment needed to:

- process influent air supply filters, hot water coils and coolers,
- supply and exhaust fans,
- dampers and controllers that ensure sufficient air flow and maintain the reactor building atmosphere at a quarter inch negative pressure, and
- isolation valves to minimize radioactivity release.

To ensure proper operation of the Emergency Core Cooling systems located within the secondary containment, air cooling units are provided to remove the heat generated by the motors, pumps and piping. There is one air cooling unit provided for each Residual Heat Removal Pump and one for each Core Spray system.

9.2.3 System Features

A short discussion of system features is given in the paragraphs which follow.

9.2.3.1 Normal Operation

Secondary containment integrity means that the reactor building is intact and the following conditions are met:

- the Standby Gas Treatment system is operable,
- all automatic ventilation system isolation valves are operable or secured in the isolated position, and
- at least one door in each access opening is closed.

In general, secondary containment integrity must be maintained at all times and can be broken only under specified conditions described in the Technical Specifications. The following typical requirements must be met when secondary containment integrity is broken:

- reactor subcritical by a specified amount
- the reactor cooled down below 212°F with the reactor coolant system vented
- no activity is being performed that will reduce the shutdown margin below that specified
- handling of spent fuel is prohibited

9.2.3.2 Abnormal Operation

In the event of a loss of coolant accident or refueling accident, all isolation ventilation dampers automatically close and remain closed for the duration of the isolation signal(s). Supply and exhaust fans trip with the same signal that starts the Standby Gas Treatment system. To mitigate the consequences of the postulated accidents three different features are utilized.

The first feature is the negative internal pressure being maintained in the secondary containment, which minimizes the ground level release of fission products by exfiltration. The secondary containment structure along with the Primary Containment Isolation system and the Standby Gas Treatment system together provide this feature.

The second feature is a low leakage containment volume, which provides a holdup time for fission product decay prior to release.

The third feature is the removal of particulate and iodine by filtration prior to release. This feature is provided by isolating the normal ventilation supply and exhaust, and routing the secondary containment atmosphere to the Standby Gas Treatment system.

9.2.4 System Interfaces

The Secondary Containment interfaces with other plant systems which are discussed in the following paragraphs.

9.2.4.1Standby Gas Treatment System

The Standby Gas Treatment system processes the secondary containment atmosphere under isolated conditions and provides leak testing capabilities.

9.2.4.2 Primary Containment

The secondary containment serves as the primary containment under specified conditions.

9.2.4.3 Primary Containment Isolation System

The Secondary Containment receives isolation signals from the Primary Containment Isolation system.

9.3 STANDBY GAS TREATMENT SYSTEM

The purposes of the Standby Gas Treatment system are:

- to process secondary containment atmosphere prior to release under accident conditions,
- to provide a means of venting the primary containment, and
- to perform leak tests of the secondary containment.

The functional classification of the Standby Gas Treatment system is that of a safety related system. Its regulatory classification is that of an engineered safety feature (ESF) system.

9.3.1 System Description

The Standby Gas Treatment system (SBGT), Figure 9.3-1, is an engineered safety feature consisting of suction ducting, two SBGT filter trains, and discharge vent ducting. Each train includes a moisture separator, a heating element, a prefilter, two high efficiency filters, a charcoal adsorber, and a blower.

The SBGT provides for treatment of the effluent atmosphere from both the primary and secondary containment. The system is arranged to utilize the normal ventilation system exhaust ducting from the primary and secondary containment. The system is actuated following the indications of a loss of coolant accident or high radiation levels in the secondary containment ventilation system exhaust, to treat and maintain the secondary containment atmosphere at a negative internal pressure.

9.3.2 Component Description

The major components of the Standby Gas Treatment system are discussed in the paragraphs which follow.

9.3.2.1 Suction Path

The SBGT is capable of processing the gaseous streams from three different systems:

- Primary Containment system (Section 9.1)
- Secondary Containment system (Section 9.2)
- High Pressure Coolant Injection system (Section 10)

9.3.2.2 Moisture Separator

The first element in the SBGT train is a moisture separator which is designed to remove any free droplets of water or mist which may be entrained in the incoming air stream. The moisture separator consists of six woven mesh modules which remove 99.9% of the entrained moisture particles 2 microns or larger.

9.3.2.3 Heating Element

The second component of each filter train is a 40-KW electric fin tube type air heater. The heating element is regulated by a humidity controller to maintain the air flow entering the prefilter at less than 70% relative humidity. If the relative humidity exceeds 70 %, the charcoal adsorption efficiency decreases.

9.3.2.4 Prefilter

The prefilter is constructed of a replaceable dry tube, extended fiberglass media, and is located in the exhaust plenum of the electric heating coil. The prefilter is designed to remove atmospheric dust and particulate matter to prevent clogging of the high efficiency filters, extending their life.

9.3.2.5 High Efficiency Particulate Air Filter (HEPA)

Immediately following the prefilter and upstream of the charcoal adsorber is the HEPA filter bank. This HEPA filter, which has an efficiency of 99.97% for particles 0.3 microns or larger in diameter, removes particulates which may enter the plenum from the suction inlets and protects the charcoal adsorber from fouling. The HEPA filter bank is composed of 6 cells constructed of fiberglass media.

9.3.2.6 Charcoal Adsorber

The charcoal adsorber bed is located between the two HEPA filters. The charcoal adsorber is impregnated with stable iodine and has a minimum capacity of removing 99.9% of iodines with 5% in the form of methyl iodine (CH_3I) when operating at <70% humidity.

9.3.2.7 Downstream HEPA Filter

Following the charcoal adsorber bed is the second HEPA filter bank. This downstream HEPA filter, which has the same design parameters as the upstream HEPA filter prevents any possible charcoal fines originating in the charcoal filter from exiting the plenum and being carried out of the plant exhaust.

9.3.2.8 Blower

The final part in the SBGT filter train is a blower. The blower is a heavy duty industrial fan unit. The SBGT blower provides the motive force required to pull the air stream through the SBGT train and then discharges the treated stream up the plant stack.

9.3.3 System Features

A short discussion of the system features is given in the paragraphs which follow.

9.3.3.1 Normal Operation

During normal plant operation, the SBGT is in a standby status ready to be started either manually or automatically. The SBGT is capable of processing air flow from the primary containment, the secondary containment, or the High Pressure Coolant Injection system gland exhaust blower.

9.3.3.2 Automatic Initiation

Both trains of the SBGT automatically start and dampers are aligned to process the air from the secondary containment, upon receipt of any of the following signals:

- low reactor water level,
- high drywell pressure,
- refueling floor area high radiation or
- reactor Building ventilation exhaust high radiation.

In addition, upon receipt of any of the above signals, the normal ventilation system isolation dampers for the secondary containment will automatically shut and the ventilation fans will trip.

9.3.3.3 Inspection and Testing

The secondary containment inleakage rate is determined by isolating the normal ventilation system and operating the SBGT. The SBGT flow is adjusted to technical specification setpoint and the secondary containment is verified to have a pressure greater than -0.25 inches water gauge below the pressure outside of the containment.

9.3.4 System Interfaces

The SBGT interfaces with other plant systems discussed in the paragraphs which follow.

9.3.4.1 Primary Containment (Section 9.1)

The Primary Containment can use the SBGT for purging operations.

9.3.4.2 Secondary Containment (Section 9.2)

The Secondary Containment uses the SBGT for testing its integrity and for maintaining >-0.25 inches of water negative internal pressure during containment isolation.

9.3.4.3 High Pressure Coolant Injection System (Section 10)

The High Pressure Coolant Injection system turbine gland seal leak off condenser exhaust blower discharges to the SBGT where the noncondensables are processed and released.

9.3.4.4 Primary Containment Isolation System (Section 9.4)

The Primary Containment Isolation system provides the automatic initiation signals for the SBGT.

9.3.4.5 Plant Stack

The SBGT discharges out the plant stack.

9.4 PRIMARY CONTAINMENT ISOLATION SYSTEM

The purpose of the Primary Containment Isolation System (PCIS) is to isolate the primary and secondary containments during accident conditions to limit the release of radioactive materials.

The functional classification of the PCIS is that of a safety related system. Its regulatory classification is that of an engineered safety feature (ESF) system.

9.4.1 System Description

The Primary Containment Isolation system determines, from information provided by reactor plant process instrumentation, which systems should be isolated during various accident or abnormal conditions. The isolation functions are initiated to ensure integrity of the containment by meeting specific design features:

- Shall be fail safe
- Any one failure will not impair the functional ability to isolate when required
- Power supplies on a set of valves shall be reliable and from different sources (i.e.: AC-DC)
- Redundancy and separation of sensors and cables
- Shall be testable during normal plant operation
- Operation must be automatic with a manual reset

The control circuitry is arranged in a dual trip system with a one-out-of-two-twice logic. In general, all piping penetrations to the primary containment, high or low energy gaseous or liquid streams, have isolations. The isolations are grouped according to valve classifications and/or the isolation signals.

9.4.2 Component Description

The major components of the Primary Containment Isolation system are discussed in the paragraphs which follow.

9.4.2.1 Isolation Valves

Isolation valves are provided to ensure containment of radioactive materials which might be released from the containment during the course of an accident. Pipes that penetrate the drywell and connect to the nuclear steam supply system are double valved, as are those that open into the drywell free space. In the case of lines forming a part of the reactor coolant pressure boundary, one valve is located inside the drywell and the other outside, as close as practical to the containment. Normally closed double valves in lines to the drywell free space, such as the vacuum relief from the Reactor Building and the suppression chamber nitrogen makeup header, are both located outside the containment. In lines forming a closed loop inside the drywell, one remote, manually-controlled, motor-operated valve is generally provided outside the drywell.

9.4.3 System Features

A short discussion of the system features is given in the paragraphs which follow.

9.4.3.1 Isolation Valve Grouping

The PCIS logic is divided into discrete groups according to the class of isolation valve.

9.4.3.2 Main Steam System Isolation

The main steam line isolation and drain valves automatically close in response to signals which indicate a breach of the reactor coolant system boundary, a gross failure of fuel cladding, or a failure of the electro hydraulic control system logic. Table 9.4-1 lists the isolation signals, any additional requirements needed, probable causes of signals, and the reason for isolation by each signal.

9.4.3.3 Other System Isolations

When a low reactor water level or a high drywell pressure is detected, the systems listed below will automatically isolate to control the loss of coolant from the reactor vessel and the radioactivity release from the primary or secondary containments.

- Drywell equipment and floor drain system
- Torus drain system
- Primary containment vent and purge system
- Secondary containment ventilation system
- Residual Heat Removal system, shutdown cooling mode

The systems listed below will also isolate upon detection of leakage from the appropriate system. For the specific isolation signals and their isolation valves refer to the sections indicated.

- Reactor Core Isolation Cooling system (Section 8.4)
- Reactor Water Cleanup system (Section 8.3)
- High Pressure Coolant Injection system (Section 10)

9.4.4 System Interfaces

The PCIS interfaces with the following plant systems to limit radioactive releases:

- Main Steam system
- Primary Containment system
- Secondary Containment system
- Shutdown Cooling mode of RHR
- Reactor Core Isolation Cooling
- Reactor Water Cleanup system
- High Pressure Coolant Injection system
- Standby Gas Treatment system

Table 9.4-1, PCIS Signals for Main Steam System

Condition Causing Isolation	Additional Requirements	Possible Cause	Reason for Isolation
Main Steam Line High Radiation	N/A	Gross Fuel Cladding Failure	Minimize Radiological Release to Environment
Main Steam Tunnel High Temperature	N/A	Steam Leak in Tunnel	Isolate the Steam Leak
Main Steam Line High Flow	N/A	Individual Steam Line Break	Attempt to Isolate the Steam Line Break
Main Steam Line Low Pressure	Mode Switch in “RUN”	EHC Pressure Regulator Failure Upscale	Prevent Excessive Reactor Vessel Cooldown Rate
Reactor Water Level Low Low	N/A	Large Loss of Coolant Accident	Conserve Reactor Vessel Water Inventory
Manual	N/A	Manual Isolation Control Switches in Closed Position	Operator Action Initiated the Isolation

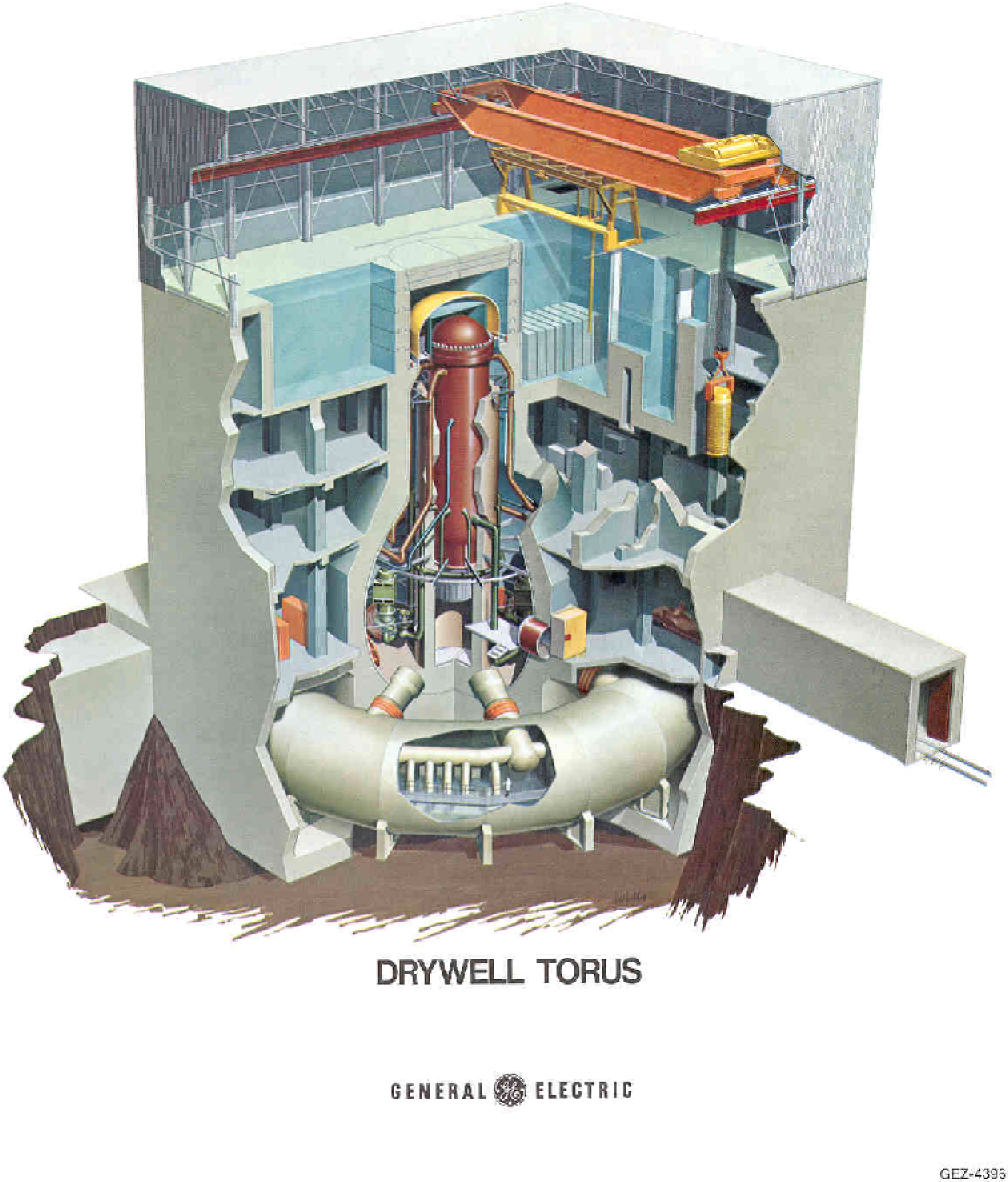
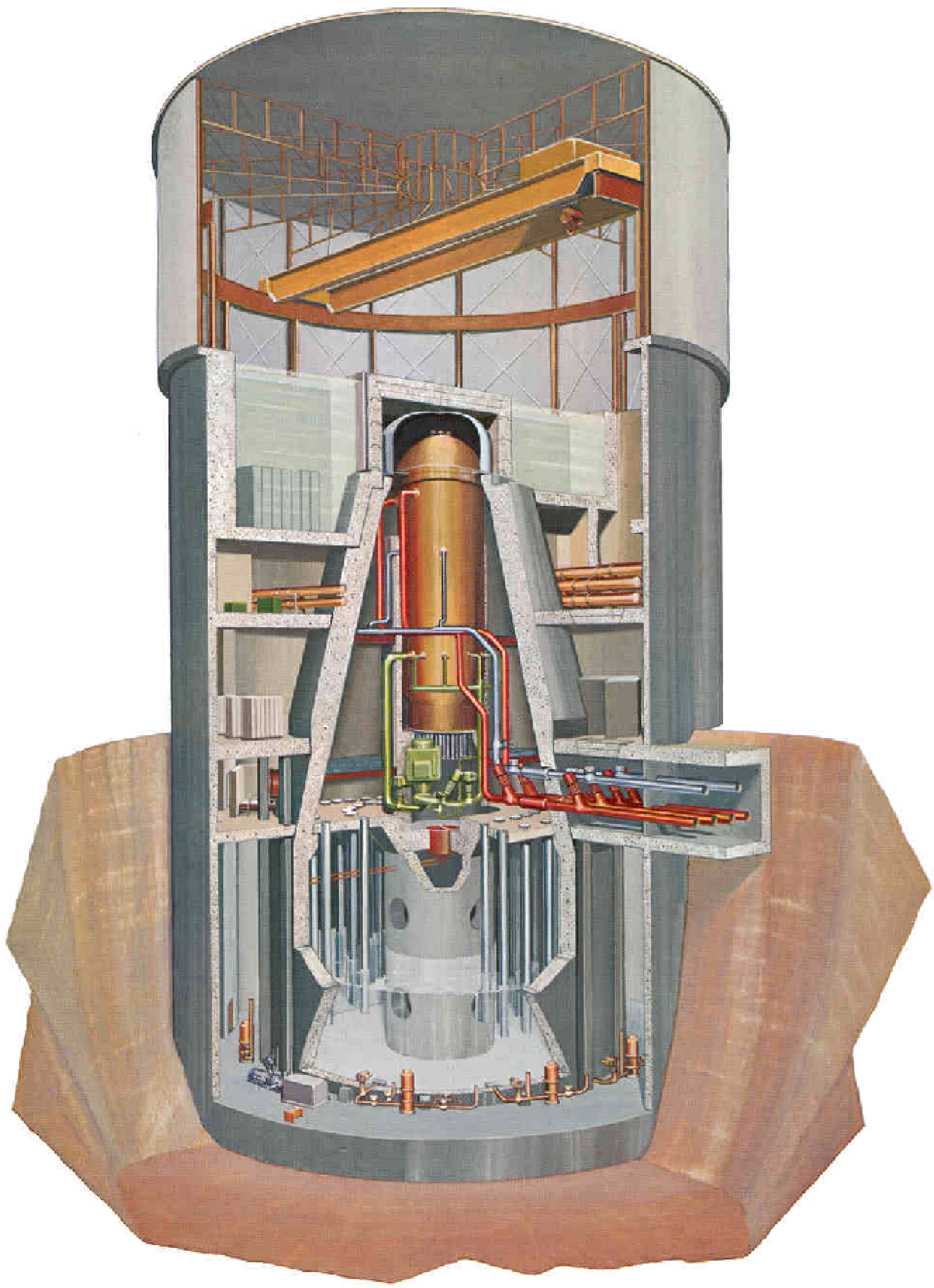


Figure 9.1-1, Mark I Containment



GENERAL ELECTRIC

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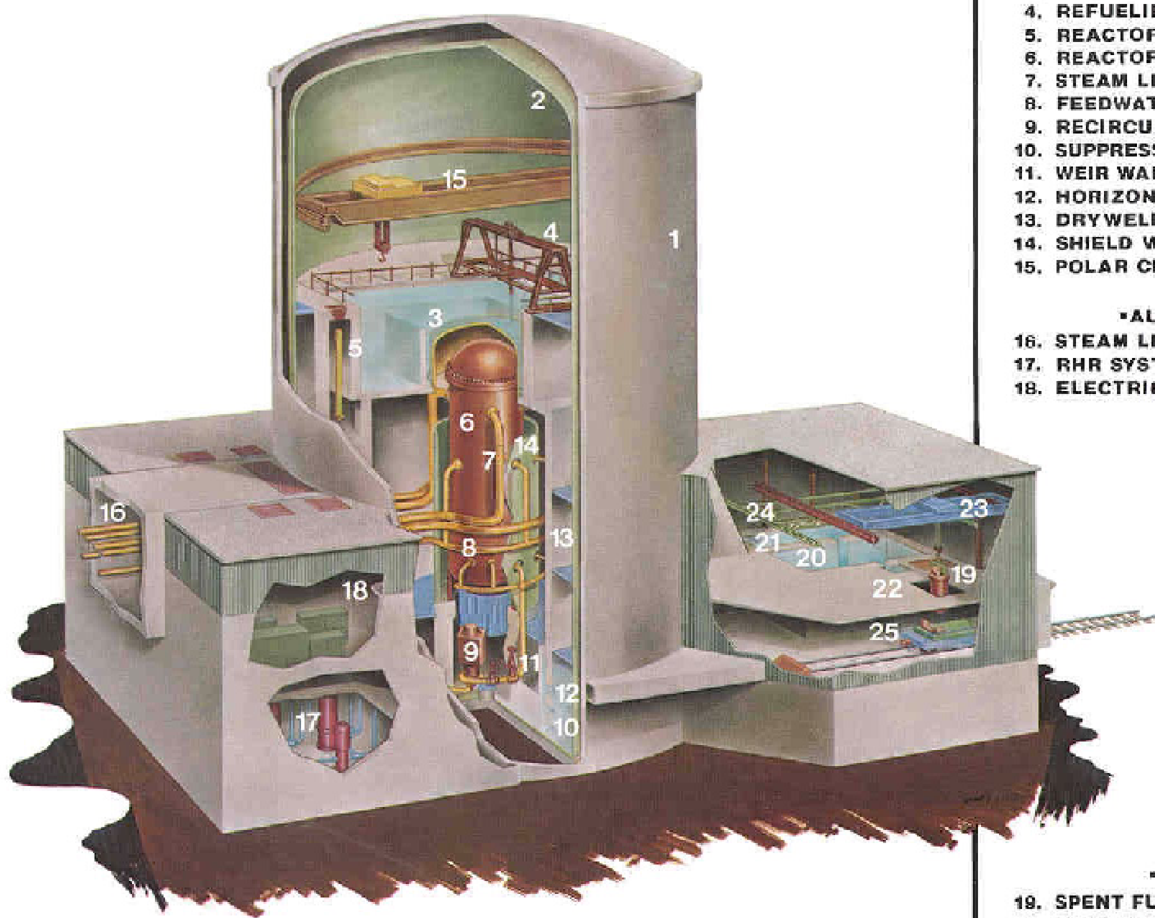
Figure 9.1-2, Mark II Containment

MARK III CONTAINMENT



GENERAL ELECTRIC

•REACTOR BUILDING•

1. SHIELD BUILDING
2. FREESTANDING STEEL CONTAINMENT
3. UPPER POOL
4. REFUELING PLATFORM
5. REACTOR WATER CLEANUP
6. REACTOR VESSEL
7. STEAM LINE
8. FEEDWATER LINE
9. RECIRCULATION LOOP
10. SUPPRESSION POOL
11. WEIR WALL
12. HORIZONTAL VENT
13. DRYWELL
14. SHIELD WALL
15. POLAR CRANE

•AUXILIARY BUILDING•

16. STEAM LINE TUNNEL
17. RHR SYSTEM
18. ELECTRICAL EQUIPMENT ROOM

•FUEL BUILDING•

19. SPENT FUEL SHIPPING CASK
20. FUEL STORAGE POOL
21. FUEL TRANSFER POOL
22. CASK LOADING POOL
23. CASK HANDLING CRANE
24. FUEL TRANSFER BRIDGE
25. FUEL CASK SKID ON RAILROAD CAR

Figure 9.1-3, Mark III Containment

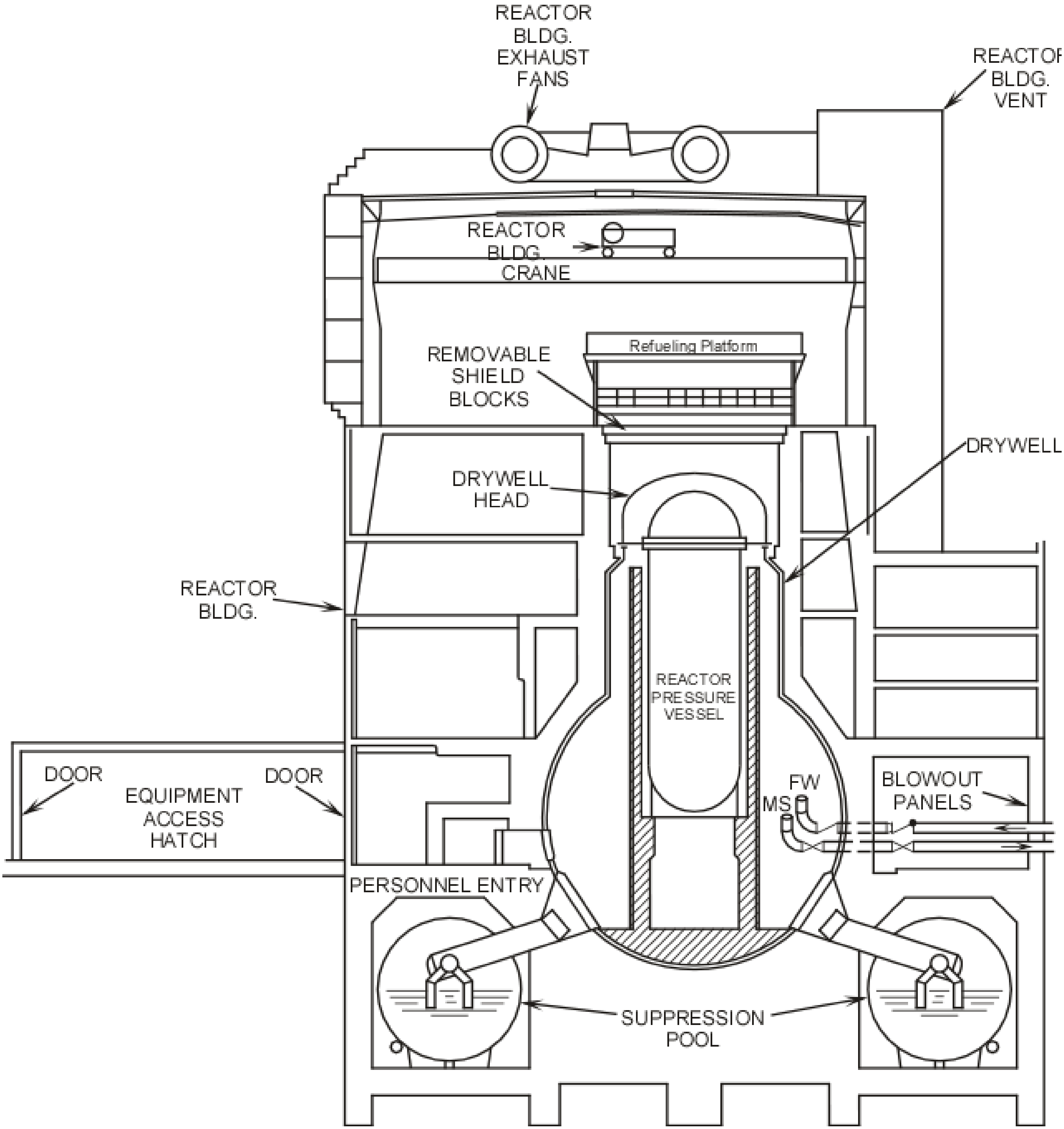


Figure 9.2-1, Secondary Containment

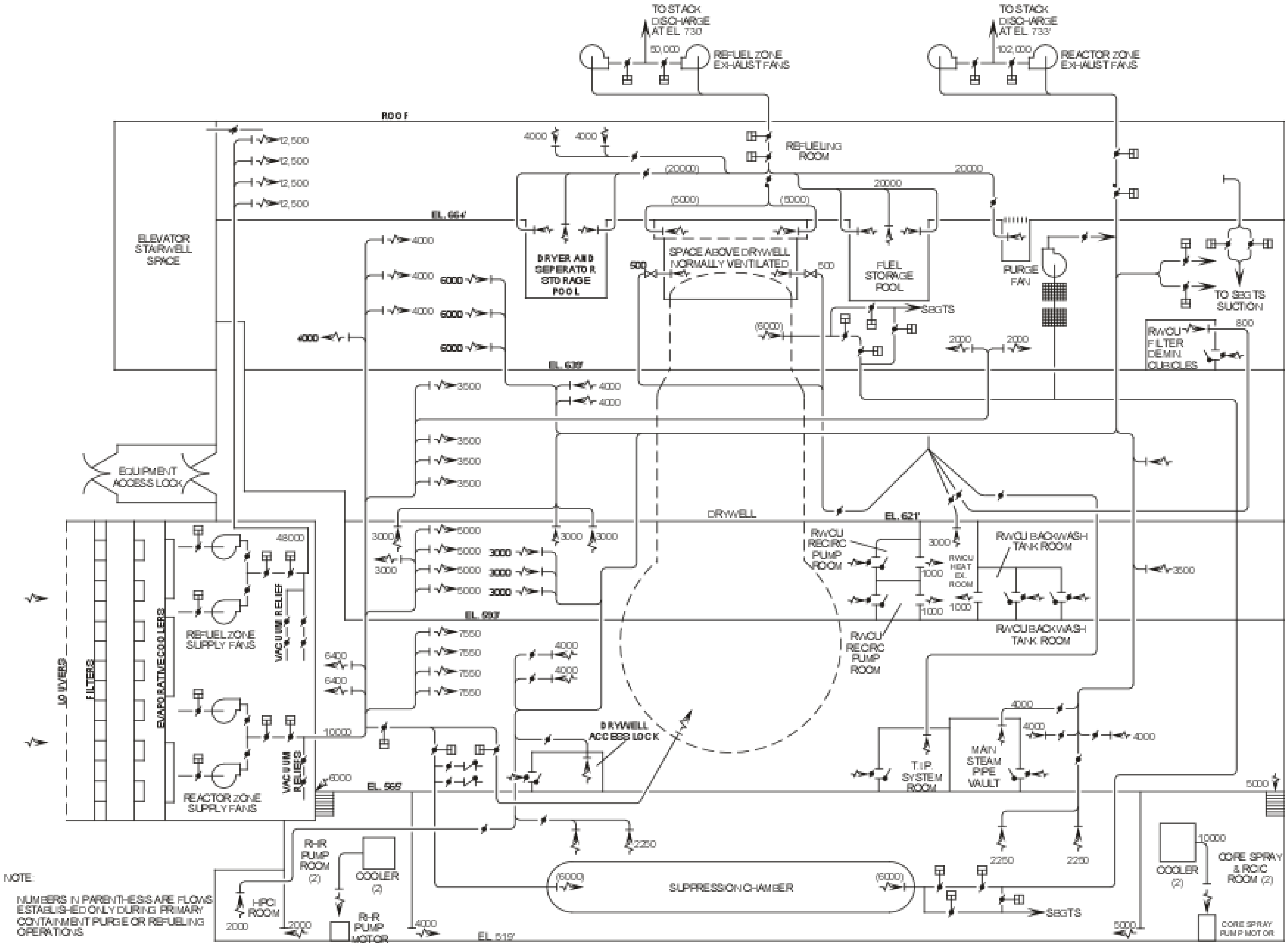


Figure 9.2-2, Secondary Containment Ventilation System

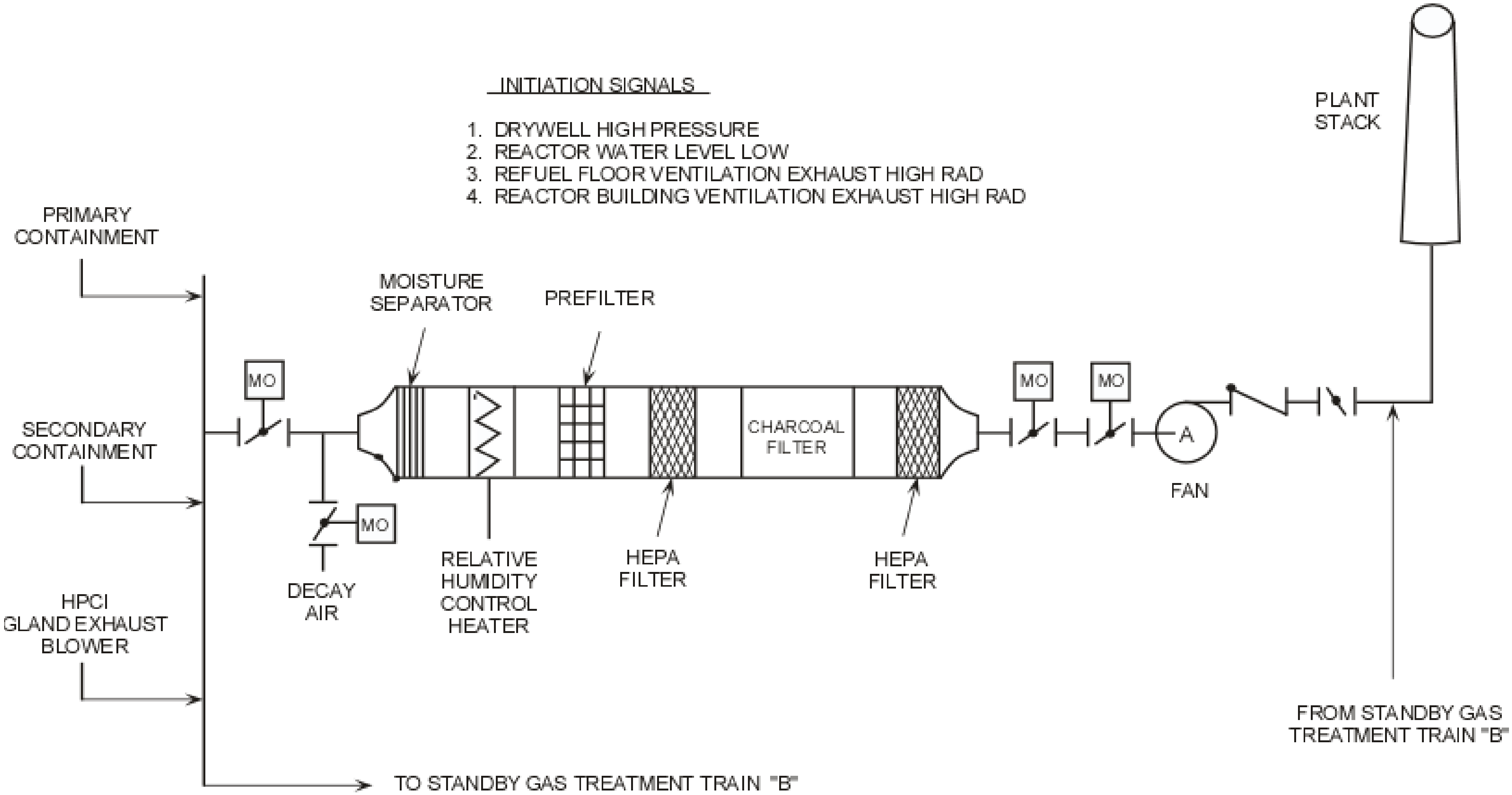


Figure 9.3-1, Standby Gas Treatment System