Westinghouse Technology Systems Manual

Section 15.3

Gaseous Radioactive Waste Processing Systems

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15.3 GASEOUS RADIOACTIVE WASTE PROCESSING SYSTEMS

Learning Objectives:

1. List both the principal volume contributors and the principal radioisotope contributors to the gaseous radioactive waste system.

2. Explain the basis for the curie limit placed on a gas decay tank.

3. Explain the reasons for using cover gas.

15.3.1 Introduction

The gaseous radioactive waste (GRW) system begins at the points of discharge from plant components or systems designed to remove radioactive gases from the reactor coolant system and related auxiliary systems. The GRW system terminates at the point of discharge into the plant ventilation exhaust system. Waste gases originate from several sources. These sources may be intermittent or continuous, depending upon plant design. The gases processed by the GRW system consist mainly of hydrogen and nitrogen, with small amounts (by volume) of fission gases. Aerated gases are not processed to preclude the formation of explosive oxygen-hydrogen mixtures.

The radioactive gases of primary interest are xenon 133 (Xe-133) and krypton 85 (Kr-85), as these are the only gases present in significant amounts which have relatively long half lives. Waste gases are generally combined in the GRW system for common treatment rather than being separated for separate treatment. There are a number of process designs which meet the performance objectives for gaseous waste systems; some of these systems are discussed in this chapter.

Each of these systems is designed to meet the following criteria:

1. Radioactive materials in gaseous effluents from the plant collectively meet the design objectives given in 10 CFR 50, Appendix I, and limits specified in 10 CFR 20.

2. The accidental release of radioactive material from a single component would not result in an off-site dose which would exceed the guidelines of 10 CFR 100. Radiation exposures to plant operation and maintenance personnel are maintained "as low as reasonably achievable."

15.3.2 System Description

The GRW system in use at most present-generation pressurized water reactor facilities is designed to collect and store gaseous waste for radioactive decay prior to controlled release to the environment. These systems consist of a combination of the following items: a collection header into which the various sources of waste gas discharge, compressors to reduce the volume of the gas, recombiners to reduce the hydrogen concentration, charcoal beds for removal of iodine, and tanks in which the pressurized gas is stored for decay prior to release. Provisions are also made to allow use of the stored gas as a cover gas for selected liquid holding tanks to prevent aeration of the fluids contained in these tanks. The various waste gas systems described in the following sections are the storage-and-release, volume-reduction, and charcoal adsorber systems. Table 15.3-1 lists the gaseous waste systems for selected Westinghouse facilities.

15.3.2.1 Storage-and-Release System

A simplified process flow diagram for the gaseous waste storage-and-release system is shown on Figure 15.3-1. With this simplified system, gases are vented from various components or systems into a vent header. The waste gases flow to a surge tank and filter unit and then to the inlet of a gas compressor.

The waste gas is compressed and then stored in any one of several storage tanks called gas decay tanks. This gas may then be reused as a cover gas or released to the environment. The gas that is to be released to the environment will be stored in a decay tank for some period of time to allow for the decay of short-lived radioactive gases.

A more detailed process flow diagram for a typical storage-and-release GRW system is shown on Figure 15.3-2. The GRW system is essentially a closed-loop system in which the gas held in the gas decay tanks may be released to the environment after a specified decay time, or be returned as a cover gas to various tanks that vent to the vent header. This cover gas is used to minimize the aeration of liquids contained in these tanks and to prevent the entry of oxygen into the GRW system. Oxygen ingress could cause explosive mixtures of hydrogen and oxygen to occur. Generally the last decay tank to receive gas will be the first decay tank used to supply the cover gas. This provides for the maximum decay time prior to releasing the gas to the environment. The various components and systems that may vent to the vent header are as follows:

- Volume control tank,
- Holdup tanks,
- Reactor coolant drain tank,
- Pressurizer relief tank,
- Chemical and volume control system,
- Gas stripper,
- Boric acid evaporator,
- Waste evaporators,
- Volume control tank gas sampler, and
- Gas analyzer return.

These tanks and components vent nitrogen, hydrogen and trace amounts of fission gases to the vent header. The waste gases collected by the vent header, as described in the previous paragraph, flow to the suction of the waste gas compressors. One of the two gas compressors is in continuous operation, with the second unit in standby to act as a backup for peak load conditions or in case of failure of the operating unit. From the compressor, gas flows through coolers to one of several gas decay tanks.

The control arrangement of the gas decay tank inlet header is designed with sufficient flexibility to allow the operator to align several tanks to perform different evolutions at the same time: one tank being pressurized, one tank in standby, one tank supplying cover gas, and one tank releasing its contents to the environment. For example, consider Tanks 1, 2, and 3 in Figure 15.3-2. Tank 1 is being pressurized by the compressors. Another tank is placed in standby, so that when the tank receiving gases from the compressors is pressurized to some specified setpoint, the inlet valve to the pressurized tank closes. This action initiates an alarm to alert the operator to place the standby tank in service. Tank 3, the last tank pressurized, is aligned to provide cover gas as explained earlier in this section. Stored gas that has decayed sufficiently is being released to the environment from Tank 2. Prior to the release the gas must be sampled and analyzed to determine the total amount of activity to be released. After analysis the gas can then be released to the plant vent at some controlled rate through a radiation monitor. If high activity is indicated in the plant vent during the release an automatic valve in the discharge line closes.

15.3.2.2 Volume-Reduction System

The volume-reduction system is essentially the same type of system as the storage-and-release system (section 15.3.2.1); the difference is that a device is incorporated into the system to reduce the volume of waste gas. This volume reduction is accomplished by recombiners which remove the hydrogen in the waste gas stream, and by re-using the nitrogen collected in the waste gas. Since hydrogen and nitrogen comprise most of the volume of waste gas, their removal results in a much smaller volume of gas to be stored. Although the system has the capability for discharge to the environment after decay, it is anticipated that no scheduled releases will be necessary over the 40-year life of the plant.

The volume-reduction system for processing waste gas consists mainly of a closed loop comprised of two waste gas compressors, two catalytic hydrogen recombiners, and gas decay tanks to store the fission-product gases (four tanks for normal at-power service and two additional tanks for service during startups and shutdowns). The process flow diagram is shown on Figure 15.3-3.

This GRW system removes fission gases from plant components and contains them indefinitely to eliminate the need for regularly scheduled discharges.

By continuous degassification of the reactor coolant at the volume control tank (VCT), this GRW system also functions to reduce the escape of radioactive gases during maintenance operations or unavoidable equipment leaks. The design is based on continuous full power operation with all gaseous fission-product leakage into the coolant associated with the 1% failed fuel criterion for the 40-year life of the plant.

Although the system is designed to eliminate regular atmospheric discharge of waste gases, disposal of radioactive gas may become necessary at some time during the plant life. Therefore, the system includes provisions to sample and isolate each of the gas decay tanks.

During normal power operation, nitrogen and fission-product gases are circulated around the GRW system loop by one of the two compressors. Fresh hydrogen gas is continuously introduced to the VCT, where it is mixed with fission-product gases which are stripped from the reactor coolant into the VCT gas space by the VCT letdown nozzle. The VCT is, in turn, continuously vented into the circulating nitrogen stream in the waste gas loop. Note that VCT pressure is determined by the hydrogen supply pressure regulator and not by the VCT purge-flow regulator.

The resulting mixture of nitrogen, hydrogen, and fission gases is directed from one of the two compressors to one of the two catalytic hydrogen recombiners, where enough oxygen is added to reduce the hydrogen to a low residual level.

The waste gas enters a recombiner package through a pressure regulator, which absorbs inlet fluctuations and maintains a constant downstream pressure of 30 psig. Gas then flows through an electrical heater which maintains it at 200 - 220°F to prevent condensed water from reaching the catalyst surface. After the gas is heated, oxygen is added, and then the gas stream enters the catalyst bed where the reaction between hydrogen and oxygen takes place.

The hot effluent stream from the recombiner vessel enters the cooler-condenser, where its temperature is reduced to 140°F or less. This two-phase mixture enters a high efficiency separator/ mist extractor where liquid particles are removed. Now free of entrained particles, the process gas is discharged from the moisture separator into the gas system through a flow control valve. The gas is then routed through a gas decay tank and sent back to the compressor suction to complete the loop circuit. Gas decay tanks 1 through 4 are alternated so that the gaseous activity (as indicated by the waste gas processing monitor) is distributed evenly among the tanks.

When gas decay tank pressure reaches about 20 psig, the recombiner back pressure control valve (flow control valve) is full open, so that no more adjustment can be made. To allow operation of the system to continue, the lineup of the system is changed to the “high pressure mode,” in which flow is from a compressor to a gas decay tank to a recombiner. This mode is suitable for operation with tank pressures up to 100 psig, and it is also used during shutdown and startup operations, with the shutdown tanks set aside for this purpose.

When the residual fission-product gases and the hydrogen contained in the reactor coolant must be removed in preparation for a cold shutdown, the VCT purge is increased to 1.2 scfm until the following criteria are met.

1. The RCS hydrogen concentration is less than 5 cc/kg, and
2. The RCS Xe-133 activity is less than 1.0 mCi/cc.

At this time, the gas decay tank which was in service during power operation is valved out, and one of the shutdown tanks is valved in. During the first plant cold shutdown, fresh nitrogen is charged to the VCT to strip hydrogen from the RCS.

The resultant accumulation of nitrogen in the shutdown tank is accomplished by allowing tank pressure to increase. During subsequent shutdowns, however, there is no additional accumulation, since the gas from the first shutdown can be reused.

Gas decay tanks 1 through 4, which are used during normal operation, are designed to contain significantly higher concentrations of fission gases than those used during shutdown. Therefore, relief discharges (not shown) from tanks 1 through 4 are relieved into one of the shutdown tanks (150 psig). The shutdown tanks, in turn, relieve directly to the plant vent header (100 psig) (not shown).

Since the system is designed to operate with no regularly scheduled discharges over the 40-year plant life, extreme care must be taken to minimize the addition of any gases other than those which the system can process and remove. Contributors in order of importance include:

- Products from theB-10 (n,α) Li-7 reaction,
- Impurities in bulk hydrogen and oxygen, and
- Stable and long-lived fission-product gases.

The system just described uses a continuous purge of the VCT. There is a refinement to this system that some plants may utilize: the use of chemical and volume control system gas stripper in lieu of the continuous purge of the VCT.

15.3.2.3 Charcoal Adsorber Systems

Another type of gaseous waste management system which may be interfaced with pressurized water reactors is the charcoal adsorber design. This design accomplishes holdup for decay of fission-product gases by adsorption on a charcoal bed, with subsequent release to the environment.

The charcoal adsorber systems are not often used in present-generation pressurized water reactor plants and will probably comprise only a small percentage of the systems of future facilities. A simplified process flow diagram of a PWR ambient charcoal system is shown on Figure 15.3-4.

The ambient charcoal system collects waste gases in the vent header in the same way as in the previously mentioned GRW systems. The gas flows to a surge tank and filter unit to the inlet of a compressor. The compressor transfers the waste gas to the charcoal adsorber beds, where the radioactive gases are held up for some time. The gases then pass through a filter unit to be released into the plant vent.

A typical GRW system using ambient charcoal is shown on Figure 15.3-5. Gases vented to the vent header are collected in the waste gas surge tank. These gases are dehumidified (moisture is removed) by the gas refrigerant dryers. The gas is then filtered by the ambient temperature charcoal adsorbers. The hydrogen and nitrogen in the gas stream passes through the adsorber beds, while the xenon, krypton, and any iodine present are adsorbed. The charcoal beds are designed to delay xenon and krypton isotopes for a sufficient time. In addition, the beds provide an iodine decontamination factor of 10^6.

After passing through the adsorber beds, the hydrogen, nitrogen, and delayed fission-product gases are processed through the waste gas compressors to the waste gas receiver tank, from which they are discharged to the environment through a radiation monitor. Provisions are also included for the recycling of the purified gas stream as a cover gas. The normal mode of operation, however, is to discharge the gas stream directly into the plant vent. There are several variations of this system, with the major differences in design being the temperatures maintained in the adsorber beds. Refrigerated systems operate at 0 - 20°F in the adsorber beds; the low temperature increases the efficiency and holdup times of the adsorber. Cryogenic systems operate at extremely low temperatures, whereby the fission-product gases are liquefied, collected, and stored on site.

15.3.3 Component Descriptions

15.3.3.1 Waste Gas Compressors

Two compressors are normally provided for removal of gases to the gas decay tanks from all equipment that contains or can contain radioactive gases. These compressors are usually of the water-sealed, centrifugal, displacement type. The operation of the compressors is automatically controlled by the compressor inlet pressure. While one unit is in operation, the other serves as a standby for unusually high flow or in case of failure of the first unit. The design discharge pressure of the compressor is 110 psig, and the design flow rate at 10 psig is 40 ft^3/min.

15.3.3.2 Gas Decay Tanks

Welded carbon steel gas decay tanks are provided to contain compressed waste gases (hydrogen, nitrogen, and fission-product gases). The total number of gas decay tanks varies from plant to plant. These tanks have a design pressure of 150 psig and have a typical volume of 600 ft^3.

The quantity of radioactive material contained in each decay tank is limited by the plant's implementation of its radioactive effluent controls program. The limit ensures that, in the event of an uncontrolled release from a single tank (such as a tank rupture), the resultant total body exposure at the exclusion area boundary does not exceed 500 mrem. This quantity of activity (considered as Xe-133 equivalent) in a single gas decay tank varies with plant location and local population density. Activity limits for single gas decay tanks for various plants are listed below:

- Zion - 22,000 curies,
- Crystal River - 47,000 curies,
- Sequoyah - 50,000 curies,
- Calvert Cliffs - 53,500 curies, and
- Callaway - 250,000 curies.

15.3.3.3 Recombiners

Two catalytic hydrogen recombiners are normally provided. Normally one recombiner is in operation, either continuously or on a batch basis. The other unit is reserved for standby. The recombiner is designed for a pressure of 150 psig and a flow rate of 50 ft^3/min. The catalyst (such as aluminum-palladium or nichrome) has a design life of approximately 15 years. The catalytic recombiner accepts a preheated waste gas mixture containing nitrogen, hydrogen and fission-product gases. Oxygen is then added to this gas mixture. As this gas flows through the catalyst, a chemical reaction takes place, combining the oxygen and hydrogen to form a water vapor. This water vapor is then condensed and removed from the system.

To ensure that the oxygen content in the GRW system is as low as practical, the recombiner operates “lean” on oxygen, thereby ensuring that all the oxygen is reacted. There is thus a trace amount of hydrogen at the outlet of the recombiner. As a result of hydrogen removal, the volume of the gas in the GRW system tends to remain constant, except for an accumulation of small quantities of fission-product gases.

15.3.3.4 Charcoal Adsorber Beds

The charcoal adsorbers are cylindrical tanks that hold beds of adsorption material. The material used for this purpose is generally activated charcoal (freed from adsorbed matter by heating). This material is selected because it is especially effective in the adsorption process due to the great surface area presented by its porous structure. Adsorption is a process that takes place at the surface of a solid (activated charcoal) that is in contact with another medium (waste gas), resulting in an accumulation of molecules (krypton, xenon, iodine, etc.) from that medium. The activated charcoal retains these gas molecules for some period of time. It is this adsorption process that allows for the decay of short-lived radioisotopes and the passing along of long-lived radioisotopes after a certain holdup or delay time.

The charcoal adsorption waste gas system is essentially the same type of system as the off-gas system utilized by boiling water reactor plants. The holdup time or adsorption resident time of the adsorption system depends on various factors, such as the type of adsorption material, the amount of adsorption material, the temperature, the flow rate, and the moisture content of the waste gas flowing through the beds. The lower the temperature, flow rate and moisture content of the waste gas (nitrogen, hydrogen and fission-product gases) flowing through a given bed, the higher the adsorption resident time of that bed.

15.3.4 System Interrelationships

15.3.4.1 Gas Analyzer

An automatic gas analyzer is provided to monitor the concentrations of oxygen and hydrogen in the various systems and tanks where an explosive mixture of oxygen and hydrogen might occur. Upon indication of a high oxygen level, provisions are made to purge the equipment to the GRW system with an inert gas.

The process flow diagram of the waste gas analyzer system is shown on Figure 15.3-6. The sample gas flows from one of the many possible sample points into the suction of the low-pressure, low-volume sample pumps (2 pumps in series). From the sample pump discharge, the gas splits into two flow streams.

One of the flow streams supplies the oxygen analyzer, and the other supplies the hydrogen analyzer. After the gases flow through the analyzers, they flow to the GRW system inlet header. The gas analyzer normally sequences through each of the sample points, but the operator may select any combination of points to be skipped or continuously sample a single point of interest. If the oxygen concentration exceeds a preselected limit (~2%), an alarm is initiated to alert the plant operators. The alarm limit provides adequate time to locate and isolate the air in-leakage before an explosive concentration is reached.

Provisions are made to periodically calibrate the analyzer using a known zero gas (nitrogen) and a known span gas (80% hydrogen, 18% nitrogen and 2% oxygen).

15.3.5 Summary

Waste gas processing systems treat waste gases that are comprised of nitrogen, hydrogen, and trace amounts (by volume) of fission-product gases. The objective of the various systems presented is to collect and store (hold up) the waste gas prior to a controlled release to the environment. This holdup time allows for the decay of short-lived radioisotopes. Therefore, the fission-product gases that are released are comprised mostly of krypton and xenon. Volume reduction is being incorporated in newer plants to increase this holdup time. Volume reduction is accomplished with the use of hydrogen recombiners. Hydrogen removal reduces the total amount of waste gases to be stored.

Table 15.3-1
Gaseous Waste Processing Systems

Plant Name	Waste Gas Compressor (scfm)	Gas Decay Tanks (cu.ft.)	Catalytic Recombiners (scfm)	Comments
R.E. Ginna	2 -	4 - (470)		
Kewaunee	2 -	4 - (470)		
Point Beach 1 & 2	2 - (1.2)	4 - (525)*		Gas stripper system used in CVCS letdown. Cryogenic gas separation system used for volume reduction.
Prairie Island 1 & 2	3 -*	9 - (470)* lo level 6 - (470)* hi level	2 - (30)* one per loop	Low level tanks used for cover gas. High level tanks used for fission gas processing.
Beaver Valley 1 & 2	2 - (2)	3 - (132)		52 cr.ft. Waste gas surge tank. 4 Charcoal Beds
J. M. Farley 1 & 2	2 - (40)	6 - (600) nor. Ops. 2 - (600) s/u & s/d	2 - (50)	
Sharon Harris	2 - (40)	6 - (600) nor. Ops. 2 - (600) s/u & s/d	2 - (50)	
North Anna	2 - (1.5)*	2 - (462)	2 - (50)	
H. B. Robinson	2 - (2)	4 - (525)		
San Onofre	1 - (2.4) 1 - (4.5)	3 - (125)		14.7 cu.ft. Waste Gas Surge Tank
V. C. Summer	2 - (40)	6 - (600) nor. Ops. 2 - (600) s/u & s/d	2 - (50)	
Surry 1 & 2		2 (434)	Installed, not used	15.7 cu.ft. Waste Gas Surge Tank

Table 15.3-1 (cont'd)
Gaseous Waste Processing Systems

Plant Name	Waste Gas Compressor (scfm)	Gas Decay Tanks (cu.ft.)	Catalytic Recombiners (scfm)	Comments
Turkey Point	2 - *	6 - (525)*		
Byron 1 & 2	2 - (40)*	6 - (600)*		
Braidwood	2 - (40)*	6 - (600*		
Calloway	2 - (40)	6 - (600) nor. Ops. 2 - (600) s/u & s/d	2 - (50)	
Catawba	2 - (40)	6 - (600) nor. Ops. 2 - (600) s/u & s/d	2 - (50)	
Comanche Peak	2 - (40) 2 - (600)	8 - (600) nor. Ops., s/u & s/d	2 - (50)	
D. C. Cook	2 - (40)*	8 - (600)*		
Diablo Canyon	3 - (40)	3 - (705)*		
McGuire 1 & 2	2 - (40)	8 - (600) nor. Ops. 2 - (600) s/u & s/d	2 - (50)	
Millstone 3		Process Gas Receiver		Letdown degassifer 120 gpm capacity 2 - 13,560 # Charcoal Beds
Salem	2 - (40)	4 - (525)		
Seabrook 1 & 2	2 - (1.2 - 11.3)			5 - 1,600 # Charcoal Beds
Sequoyah 1 & 2	2 - (40)*	9 - (600)*		

Table 15.3-1 (cont'd)
Gaseous Waste Processing Systems

Plant Name	Waste Gas Compressor (scfm)	Gas Decay Tanks (cu.ft.)	Catalytic Recombiners (scfm)	Comments
Trojan	2 - (39)	4 - (600)		
Vogtle	2 - (40)	7 - (600) nor. Ops. 2 - (600) s/u & s/d	3 - (50)	29 cu.ft. Waste Gas Surge Tank
Wolf Creek	2 - (40)	6 - (600) nor. Ops. 2 - (600) s/u & s/d	2 - (50)	
Zion 1 & 2	2 - (40)*	Cement		

* common to both units

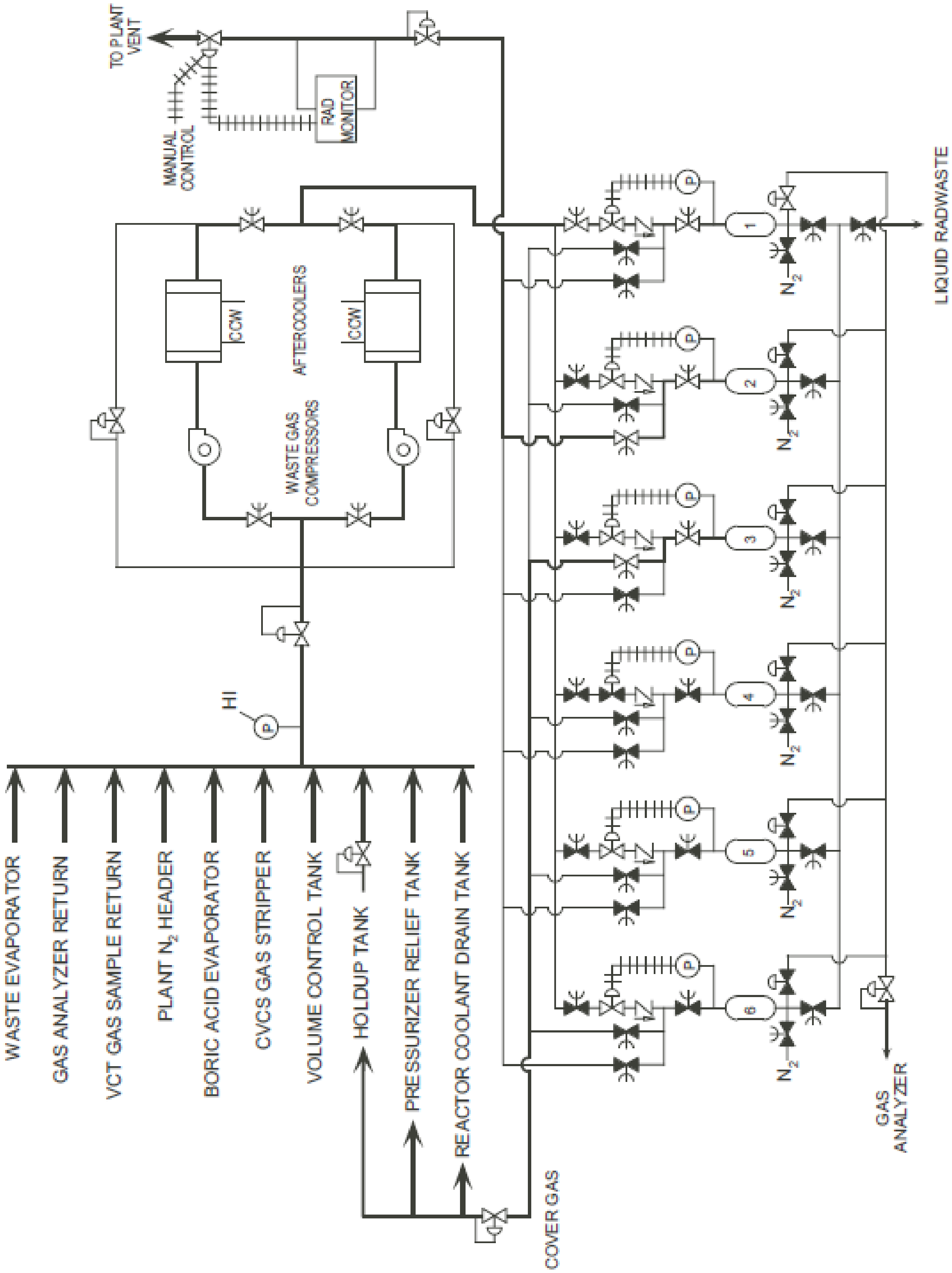

Figure 15.3-2 Gaseous Waste Processing System

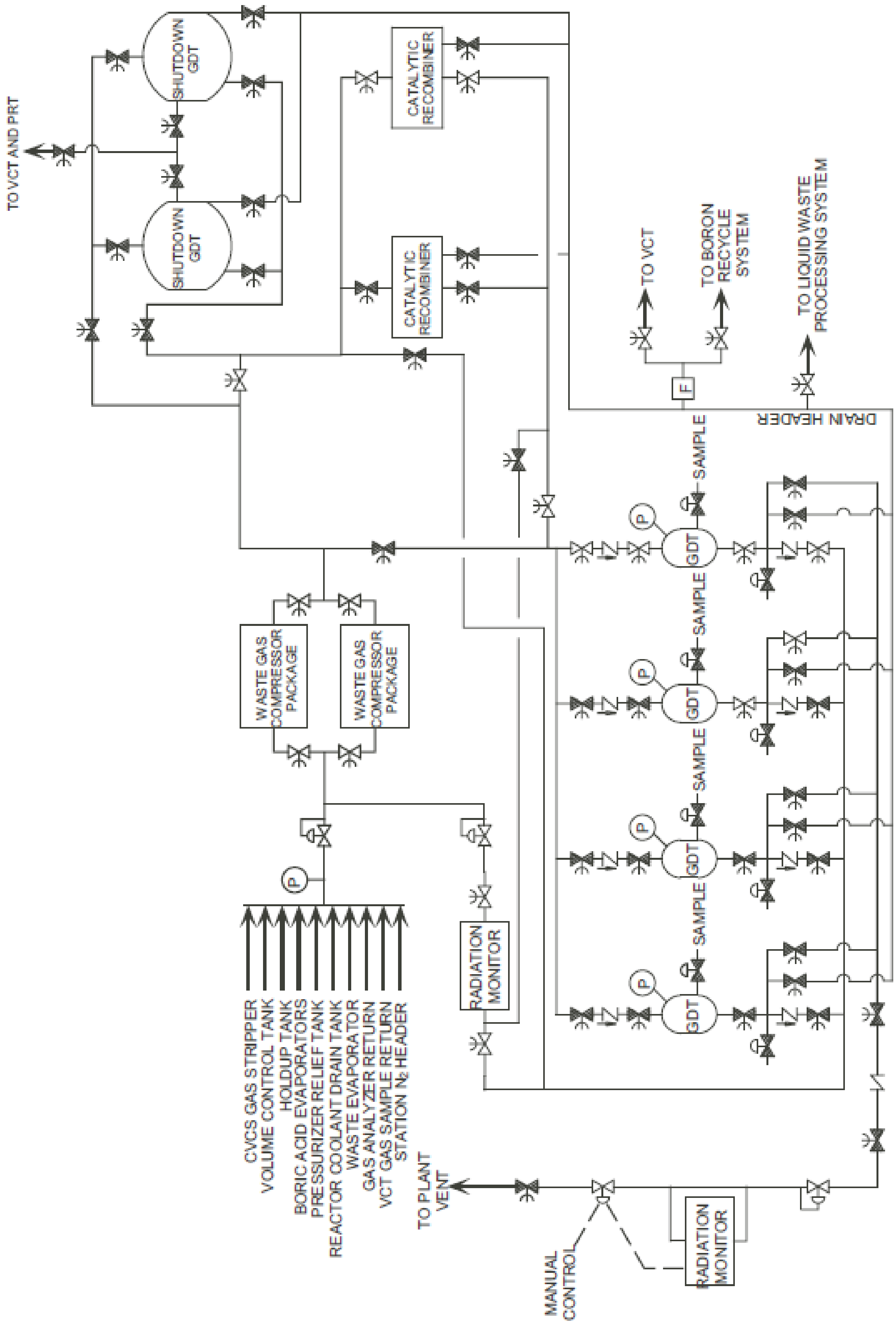

Figure 15.3-3 Gaseous Waste Processing with Recombiners

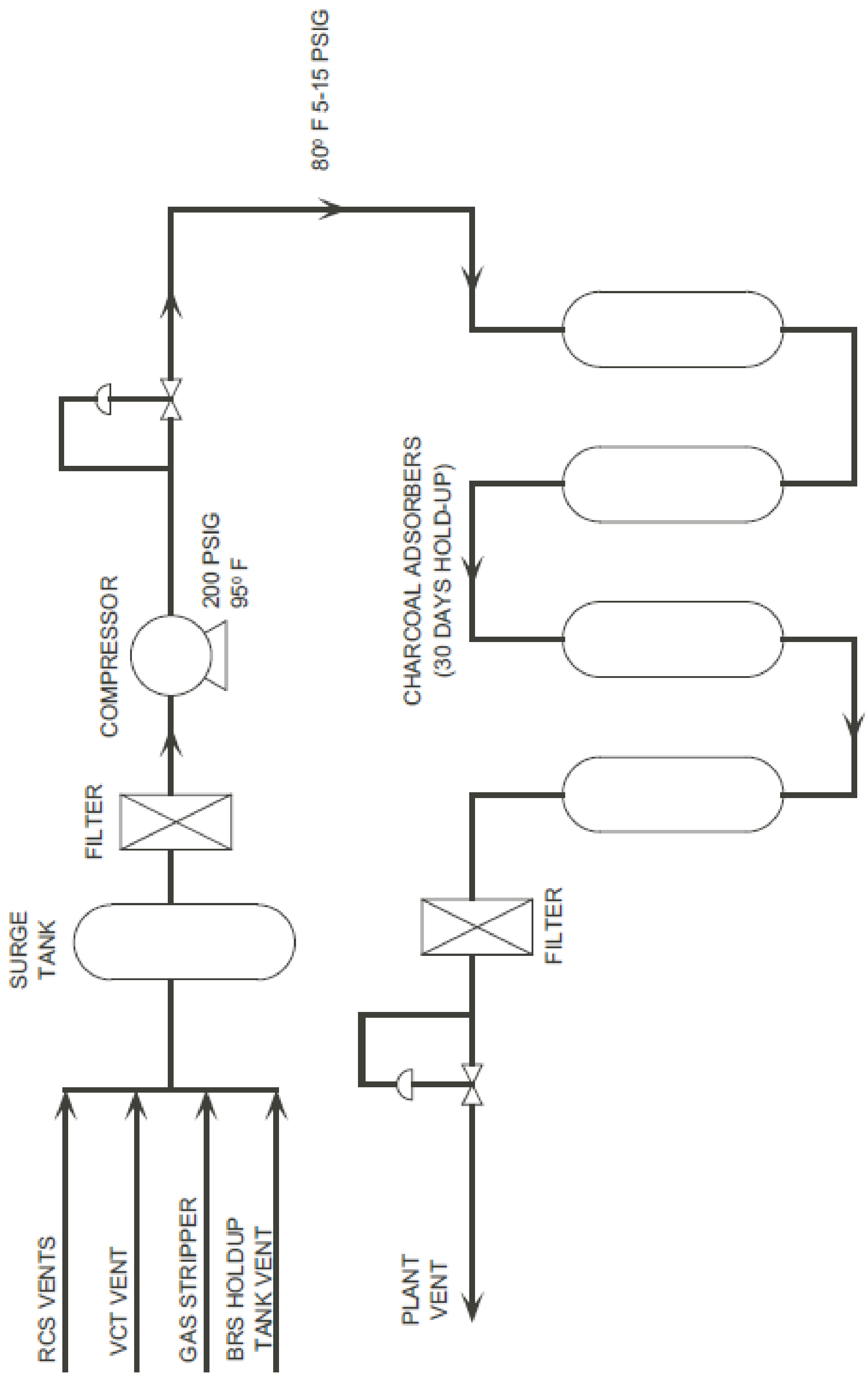

Figure 15.3-4 PWR Ambient Charcoal

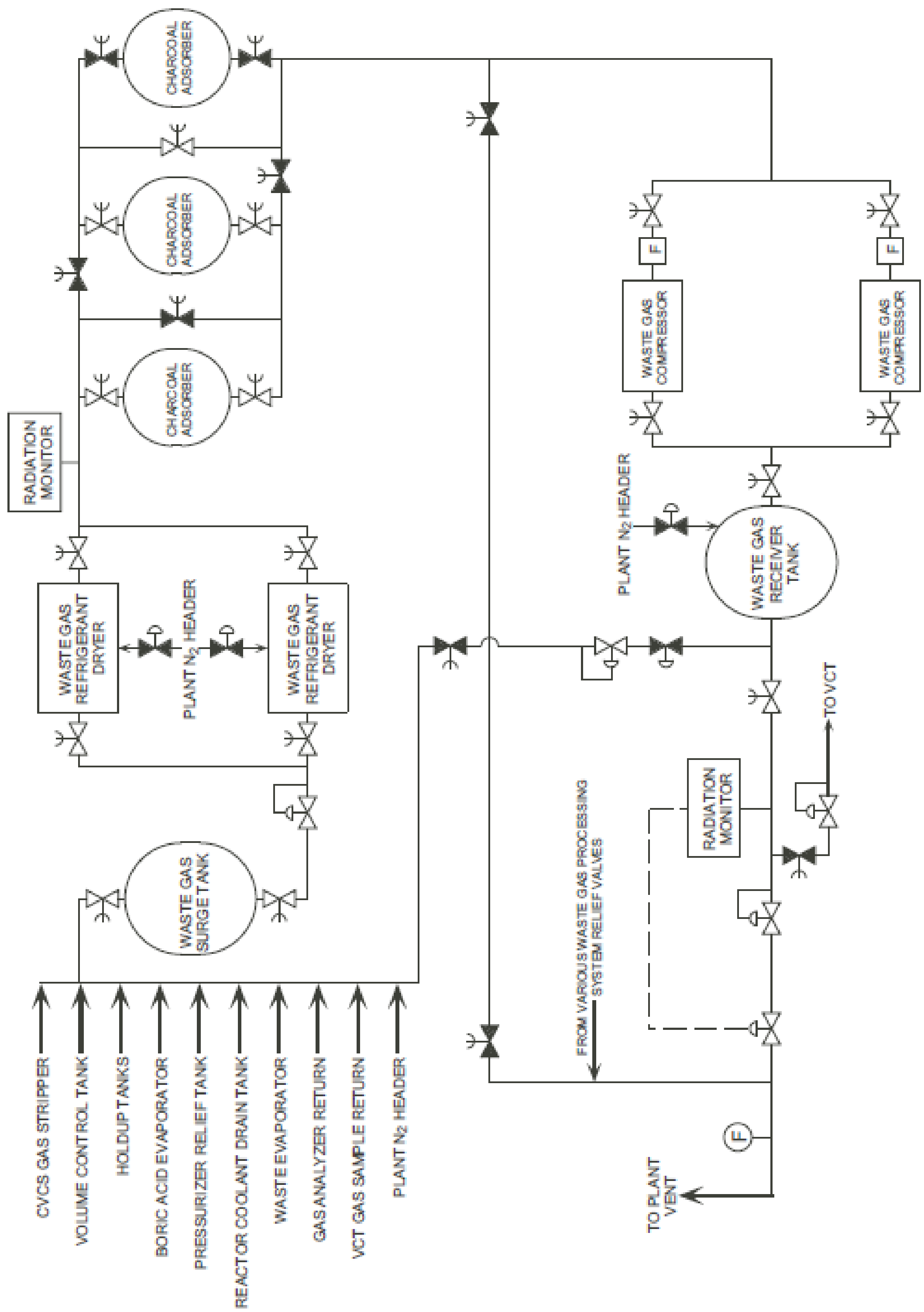

Figure 15.3-5 Gaseous Waste Processing System with Ambient Charcoal

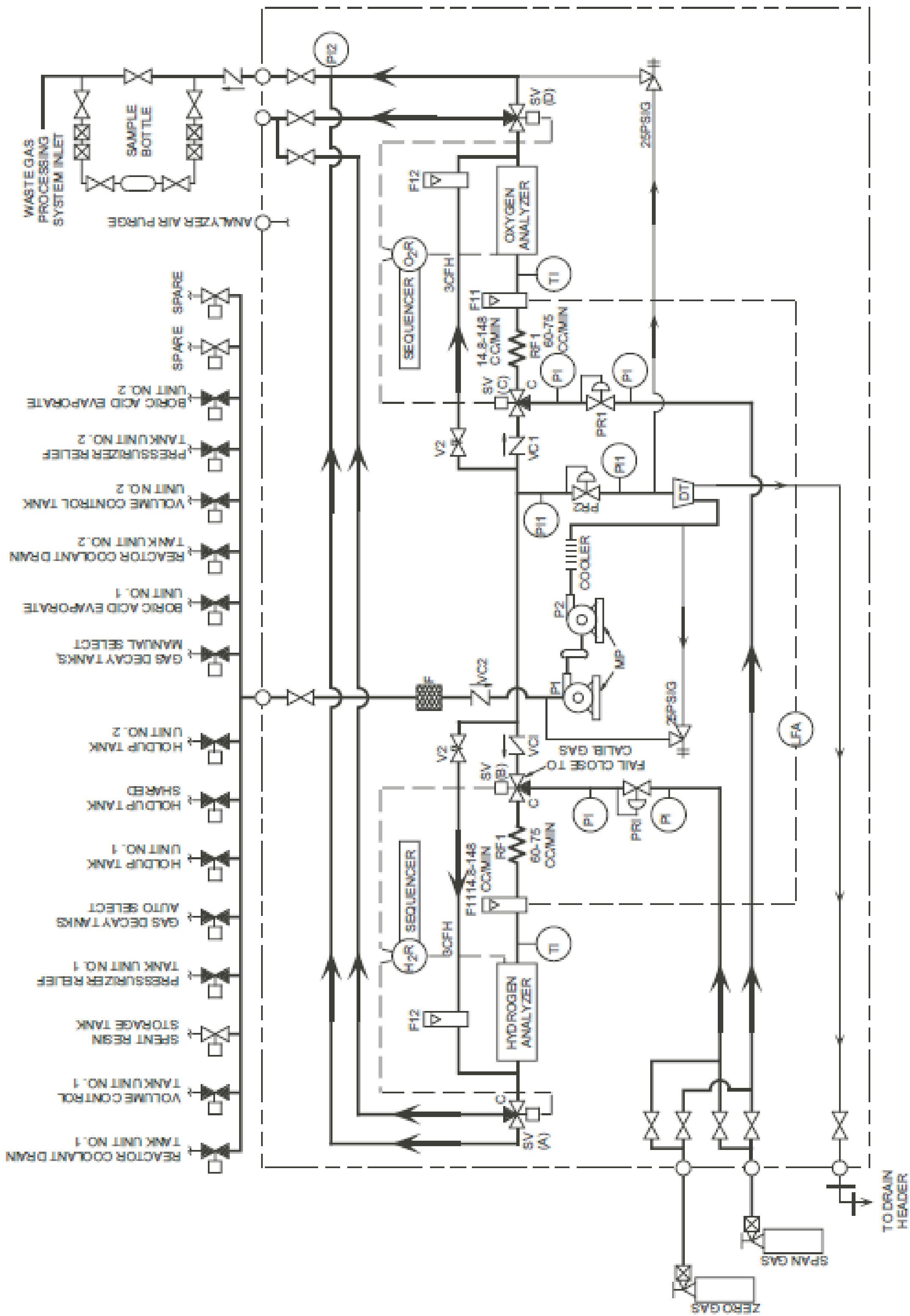

Figure 15.3-6 Gas Analyzer System