7.0 GASEOUS RADWASTE SOURCES

Fission and activation gases are generated during nuclear power plant operation. The gases are dissolved in the reactor coolant and transported to various areas throughout the plant as a result of waste processing and associated leakage of those systems. The gases are not completely soluble in the coolant and, consequently, system leakage leads to dispersal of fission gases, and possibly particulates, into the plant environs. This becomes a potential contribution to plant effluent via the ventilation system. Radioactive gases are usually held for radioactive decay for the purpose of minimizing radioactivity released to the environment. In addition, radionuclides in the form of particulates can be airborne and are included in the gaseous radwaste stream. The release points and magnitude of release from those points depends on the type of reactor (PWR/BWR) and the plant design. Typical gaseous and airborne particulate source terms are identified for PWRs in Tables 7.1-1 and 7.1-2 and for BWRs in Table 7.1-3. The principal sources of gaseous waste generation are highlighted in Table 7.1-4.

Gaseous waste systems are designed to retain the fission and activation gases for radioactive decay to extremely low levels prior to release. Retention methods include storage in pressurized tanks, long delay lines and holdup through absorption in charcoal beds. Other methods of processing gaseous waste are being evaluated and functionally tested. They include cryogenic systems and permanent holdup in high pressure containers.

The components containing the high activity level gases are separated and shielded for operation and maintenance of individual components. In PWR's the gas is retained in pressurized tanks for months, or longer. A number of BWR's utilize a recombiner to reduce the gaseous waste volume prior to delay in the holdup piping. Any gas retention system requires radiation monitors that are capable of not only monitoring planned releases, but also detecting leakage, breakthrough or other inadvertent release. Provisions are made for obtaining representative grab samples from the discharge side of the retention system.

7.1 FISSION PRODUCTS

Gaseous fission products include noble gases such as xenon (Xe) and krypton (Kr). During the nuclear fission process many fission products are produced. Some of the gaseous fission products are released into the reactor coolant system due to: (1) defects in the fuel cladding; and, (2) transport through the fuel cladding in accordance with Sievert's Law. These products include the noble gases (Kr, Xe) and radioiodine. The radioiodine can exist in various chemical forms such as I_2, IO_3, HOI, and CH_3I.

7.2 ACTIVATION PRODUCTS

Activation products are also a direct result of the nuclear fission process. Principal activation gases include nitrogen, oxygen, argon, and tritium. In addition, numerous particulates are also activated. These particles include the normal radionuclides found in both solid waste and liquid waste streams. A listing of specific activation products that commonly occur in PWRs and BWRs is includedin Table 3.1-3 found at the end of Chapter 3.

7.3 REGULATIONS GOVERNING GASEOUS RADWASTE IN LWRS

The regulations applicable to Gaseous Radioactive Waste Systems are:

- 10 CFR 50
  - Design objectives for radwaste systems based on annual maximum dose
  - Cost/benefit criteria for modifications to the radwaste system

- 40 CFR 190
  - Limits on annual dose from the entire uranium fuel cycle

- 10 CFR 20
  - Maximum concentrations in unrestricted areas

- Technical Specifications
  - A variety of requirements including limits on releases.

7.3.1 Processing Systems

Gaseous radioactive waste processing systems must be designed to operate in a manner that meets the design objectives contained in 10 CFR Part 50 Appendix I (Numerical Guides for Design Objectives and Limiting Conditions for Operation to Meet the Criterion "As Low As Is Reasonably Achievable" for Radioactive Material in Light-Water-Cooled Nuclear Power Reactor Effluents) and 40 CFR Part 190 (Environmental Radiation Protection for Nuclear Power Operation). Control and monitoring of the release of radioactive materials to the environment from waste processing systems are governed by the design objectives outlined in 10 CFR Part 50.34a (Design Objectives for Equipment to Control Releases of Radioactive Material in Effluents - Nuclear Power Reactors) and Criteria 60 and 64 contained in Part 50 Appendix A of 10 CFR 50 (General Design Criteria for Nuclear Power Plants). The gaseous radwaste processing system must also be designed to accommodate accidental releases.

7.3.2 Effluent Discharge

Releases of radioactive gases in effluents to unrestricted areas are governed by the requirements in 10 CFR 20.1302 and technical specifications. Power reactor technical specifications prohibit releases of radioactive gases in concentrations that exceed the limits established in Table 2, Appendix B of 10 CFR 20. However, for licensees other than power reactors, Part 20 allows the releases to be averaged over a time period not to exceed one year.

7.4 RELEASE PATHWAYS

The nature and amount of gaseous radwaste generated from the normal operation of a LWR is dependent on various factors such as: the type of reactor (BWR or PWR); specific design features of the reactor; operating conditions; and integrity of the fuel. Reactor type is the major factor in determining the specific sources of gaseous radwaste. Therefore, release pathways are discussed separately for each type of reactor.

7.4.1 PWR Gaseous Release Pathways

During PWR operation, gaseous wastes originate from:

- Degassing reactor coolant and purging the Volume Control Tank
- Displacement of cover gases as liquids accumulate in various tanks
- Equipment purging
- Sampling operations and automatic gas analysis for hydrogen and oxygen in cover gases.

The waste gas processing system receives input from both continuous stripping of the primary coolant during normal operation and from degassing the primary coolant which is accomplished during cold shutdown.

Gas stripping and radioactive decay in the primary coolant are the two primary gaseous activity removal mechanisms in a PWR. Holdup of radioactive gases in the waste gas processing system is normally accomplished by storage in pressurizing tanks or by a charcoal delay system.

Ventilation system releases result primarily from leakage from the primary coolant system. Gases from these leaks enter the containment and auxiliary buildings. In addition, fine particles of radioactive material could also become airborne in these buildings. These gases and airborne materials enter the ventilation effluent air stream.

7.4.2 BWR Gaseous Release Pathways

Potential release pathways from a gaseous radwaste processing system are:

- Treated effluent
- Main condenser evacuation
- Turbine gland seal condenser vent
- Main condenser vacuum pumps
- Building ventilation vents/exhausts

The main condenser evacuation system is the principal BWR release pathway. Noble gases and radioiodine are transported with the steam from the reactor vessel and are normally vented from the main condenser through the air ejector. There are mechanical vacuum pumps within this system that are used to establish main condenser vacuum during startup. These pumps also maintain a slight negative pressure in the main condenser during shutdown. The effluents in these pumps contain radioactive gases as a result of this operation.

The turbine gland seal system provides another pathway for release. The turbine gland seal system is designed to prevent air leakage into the turbine via the turbine shaft. Steam is used as the seal. Older BWRs, however, use main steam that contains radioactive gases, which are released to the environment through the gland seal condenser vent. Newer BWRs use nonradioactive steam from auxiliary boilers to provide this seal.

Finally, exhausts from building systems are ventilated into the plant exhaust system. These exhausts contain radioactive gases or suspended particulates that can leak to the environment.

7.4.3 Comparison for PWR and BWR Gaseous Radwastes

The principal difference between the gaseous waste treatment systems for BWRs and PWRs is the need to handle large amounts of hydrogen and oxygen generated by radiolysis in the BWR. Radiation separates water molecules into hydrogen and oxygen atoms. These atoms enter the gas phase of the BWR cycle and are stripped off in the steam jet air ejector. The design flow rate into the Off Gas System for a typical 1100 MW(e) reactor is 265 scfm, of which 225 scfm is hydrogen and oxygen and the other 40 scfm is mostly air in-leakage. Conversely, a PWR normally produces about 1 scfm from the gas stripper, with occasional larger amounts during waste tank filling.

7.5 GASEOUS RADWASTE PROCESSING

Gaseous radioactive waste effluents are processed by:

- Particulate filtration
- Gas adsorption
- Decay in hold-up tanks

Some filtration units are designed to remove particulates from the air (e.g., High Efficiency Particulate Air Filters, HEPA). Charcoal adsorption is designed to remove gases from the air. Hold-up tanks contain fission product gases for decay and eventual release. Typical PWR gaseous waste processing systems are illustrated in Figures 7.5-1 through 7.5-5. The BWR off gas system is discussed in detail in Section 7.9 of this chapter. The PWR gaseous waste disposal system and the components that comprise such systems are discussed below.

PWRs have relatively small gas volume (15 cfm) that lend to batch processing; whereas, BWRs have high gas volumes (250 cfm) that make a continuous processing system necessary.

As in the case of liquid waste processing systems, specific information on a facilities gaseous waste system is described in the facility FSAR and its amendments.

The remainder of section 7.5 focuses primarily on PWRs. However, some of the material in this section would apply to BWRs as well.

7.5.1 PWR Gaseous Radioactive Waste Processing System

In a PWR, the primary treatment of waste volumes is by decay and filtration.

The gaseous waste system begins at the point of discharge from plant components or systems designed to remove radioactive gases from the reactor system and related auxiliary

systems, and terminates at the effluent exhaust system. These sources are intermittent or continuous depending upon plant design, and include:

- Plant nitrogen header
- CVCS gas stripper
- Volume Control Tank
- Holdup tanks
- Boric acid evaporators
- Pressurized relief tank
- Reactor coolant drain tank
- Waste evaporator
- Gas analyzer return
- VCT gas sample return

During PWR operation, gaseous wastes originate from:

- Degassing reactor coolant and purging the volume control tank
- Displacement of cover gases as liquids accumulate in various tanks
- Equipment purging
- Sampling operations and automatic gas analysis for hydrogen and oxygen in cover gases.

Aerated gases are not processed to preclude the formation of combustible hydrogen-oxygen mixtures.

Waste gases are generally combined in the waste gas system for common treatment rather than separating the gases for separate treatment. There are a number of process designs that meet the performance objectives for gaseous waste systems. Some of these different designs are discussed.

The gaseous waste processing systems in use at most present generation facilities are 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:

- Collection header into which the various sources of waste gas discharge
- 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 are:

- Storage and release
- Volume reduction
- Charcoal absorber systems.

Table 7.5-1 lists the gaseous waste systems for selected Westinghouse facilities.

7.5.1.1 CVCS Gaseous Waste Processing

Most of the gas received by a PWR gaseous waste processing system (Figures 7.5-1 and 7.5-2) during normal operation is cover gas displaced from the Chemical and Volume Control System Holdup Tanks as they fill with liquids. The gaseous wastes consist primarily of hydrogen stripped from coolant discharged to the CVCS holdup tanks during boron dilution, nitrogen, and hydrogen purges from the CVCS volume control when degassing the reactor coolant and nitrogen from the closed gas blanketing system. The gas stripper in the Boron Recovery System is a major source of gaseous waste.

Fission gases constitute only a small fraction of the gas volume processed by the gaseous waste processing system at a PWR.

The radioactive gases of primary interest are xenon-133 and krypton-85. These are the only gases present in significant amounts that have relatively long half-lives.

The cover gas must be replaced when the tanks are emptied during processing; therefore, facilities are provided to return the gas from the decay tanks to the holdup tanks. The gas decay tank capacity permits a minimum of 45 days decay of waste gas before discharge. A backup supply from the nitrogen header is provided for makeup if return flow from the gas decay tanks is not available.

The hydrogen concentration could exceed the combustible limit; thus components discharging to the vent header system are restricted to those containing no air or aerated liquids and the vent header itself is designed to operate at a slight positive pressure (between 0.5 and 3.0 psig) to prevent in-leakage. Out-leakage from the system is minimized by using diaphragm valves, bellows seals, self contained pressure regulators and soft-seated packless valves throughout the radioactive portions of the system.

Gases vented to the vent header flows to the waste gas compressor suction header. One of the two compressors is in continuous operation with the second unit as a backup for peak conditions. From the compressors, gas flows to one of the four large gas decay tanks. The control arrangement on the gas decay tank inlet header allows the operator to place one large tank in service and to select a second large tank for backup. When the tank in service is pressurized to capacity, a pressure transmitter automatically opens the inlet valve to the backup tank, closes the inlet to the filled tank, and annunciates an alarm to alert the operator to select a new backup tank.

The header arrangement at the tank inlet gives the operator flexibility to fill, reuse, or discharge the gas to the environment simultaneously with restriction of operation of the other tanks.

Normally six small decay tanks are available for use during degassing of the reactor coolant prior to shutdown. The reactor coolant fission gas activity inventory is distributed equally among the six tanks through a common inlet header.

Before a tank is discharged to the environment, its contents are sampled and analyzed to verify sufficient decay and to provide data to document the release at a controlled rate.

7.5.1.2 PWR Storage and Release Gaseous Radwaste System

A simplified process flow diagram for the storage and release type radioactive gas waste system is shown in Figure 7.5-3. This system vents gases from various components into a vent header. The waste gas flows to a surge tank and filter unit, then to a gas compressor.

The waste gas is compressed and stored in any one of several storage tanks (Gas Decay Tanks). This gas is reused as a cover gas or released to the environment. Prior to release to the environment, it is held in the Decay Tank for sufficient time to permit the decay of short-lived radioactive gases.

This waste gas system is essentially a closed loop system in which the gas is held until in the Decay Tanks for some specified time for decay or is 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 entry of oxygen into the waste gas system (oxygen could lead to an explosive mixture with hydrogen in the system). Generally the last Decay Tank to receive gas is used to supply the cover gas. This maximizes decay time prior to discharge.

The various components and systems that vent to the vent header are:

- Volume Control Tank (VCT)
- Holdup Tanks
- Reactor Coolant Drain Tank
- Pressurizer Relief Tank
- CVCS
- Gas Stripper
- Boric Acid Evaporator
- VCT Gas Sampler
- 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 flow to the suction of the waste gas compressors. A compressor is in continuous operation. From this compressor, the gas flows through coolers to one of several Gas Decay Tanks.

The control arrangement of the Gas Decay Tank inlet is designed with sufficient flexibility to allow alignment of several tanks to perform different evolutions simultaneously. One tank can be receiving; another discharging, while a third is being pressurized and others are providing cover gas or are on standby. If the contents of a tank has decayed sufficiently it is released at a controlled rate after sampling and analyses of its contents. The release is monitored by the radiation monitoring system and is automatically terminated if it exceeds prescribed limits.

7.5.1.3 Volume Reduction System

The volume reduction system is essentially the same type of system as the storage and release system. The difference is a hydrogen recombiner is introduced into the processing stream to remove hydrogen and thereby reduce the waste gas volume. Hydrogen, along

with nitrogen, constitutes a major portion of the waste gas stream. By eliminating the hydrogen and reusing the nitrogen, the volume of gas to be stored is much smaller. The use of this approach typically negates the need for scheduled discharge of any radioactive gases over the operating life of a nuclear power station. Nevertheless, provisions are included for isolation and sampling should a discharge be warranted.
The volume reduction system consists principally of a closed loop with:

- Two waste gas compressors
- Two hydrogen recombiners
- Gas decay storage tanks

The process flow for this approach is shown in Figure 7.5-4.

By continuous degassing of the reactor coolant at the VCT, the waste gas system reduces escape of radioactive gases during maintenance and from equipment leakage.

During normal operation, nitrogen contaminated with fission gases is circulated throughout the waste gas system loop by one of the compressors. Fresh hydrogen is continuously introduced to the VCT, where it is mixed with the fission gases stripped from the reactor coolant into the VCT gas volume via the VCT letdown line nozzle (the hydrogen addition is to scavenge oxygen and maintain reducing conditions in the reactor coolant). This gas is subsequently circulated via a compressor to the recombiner to reduce the hydrogen to a low residual level.

The gases enter the recombiner package through a pressure regulator to absorb inlet fluctuations and maintain a constant downstream pressure (about 30 psig). The gases in the recombiner package flow through an electrical heater to maintain a temperature of 200 - 220^{o} F and prevent condensed water from reaching the catalyst surface. Oxygen is added to the gas downstream of the heater before the stream enters the catalyst bed. In the catalyst bed, the hydrogen and oxygen combine to form water.

The temperature of the hot effluent stream is reduced to 140^{o} F in the cooler condenser before entering a high efficiency separator-mist extractor as a two phase mixture. Any liquid particles are removed and the stream passes through a flow control valve into the gas system. The gas is routed through the gas decay tank back to the compressor suction to complete the circuit.

Removal of residual fission gases and hydrogen in the reactor coolant in preparation for a cold shutdown is achieved by increasing the VCT purge rate to 1.2 scfm until:

- RCS hydrogen concentration is <5 cc/kg
- RCS xenon-133 activity is <1.0 µCi/cc.

When these criteria are met, the gas decay tank in service is isolated and another tank is placed in service. Nitrogen accumulated during hydrogen purge from the first cold shutdown is reused during subsequent cold shutdowns, resulting in no additional accumulation of this gas.

A refinement of this approach uses the CVCS gas stripper in lieu of continuous purge of the VCT (Figure 7.5-4).

7.5.1.4 Charcoal Adsorber System

A charcoal adsorber system can be interfaced with the PWR gaseous waste system to holdup the fission gases for decay prior to discharge. It is used at a few PWRs. A simplified process flow diagram of a PWR ambient temperature charcoal system is provided in Figure 7.5-5.

The ambient charcoal system collects gas in the same way as in the other waste gas systems. The gas flows to a surge tank and filter unit, to the inlet of a compressor and is transferred to the charcoal adsorber beds where the radioactive gases are held for some period of time. After passing through a filter unit, the gases are released to the plant vent. A typical system using ambient charcoal is shown in Figure 7.5-6. Gases vented to the vent header are collected in the waste gas surge tank. They are dehumidified by the gas refrigerant system. The gas is then filtered and the noble gases and iodine are removed by the charcoal absorbers. Hydrogen and nitrogen pass through the bed. This delays xenon and krypton isotopes. A Decontamination Factor (DF) of 10^6 is obtained for iodine during gas stream passage through the charcoal beds.

The hydrogen, nitrogen, and delayed fission gases are processed through the waste gas compressors to the waste receiver tanks. They are subsequently discharged to the environment.

The gases can be recycled for use as a cover gas, but normally they are discharged directly into the plant vent.

There are several variations of this approach, including the use of chilled charcoal beds or cryogenic collection.

In addition, containment purge and building ventilation contribute to airborne radioactive effluent. These streams are discussed in Chapter 1 under ventilation systems. These streams are discharged directly from plant release point(s) after filtration and charcoal adsorption. They are not processed through the gas decay system.

7.5.1.5 System Components

The major components of the PWR gaseous waste disposal system are:

- Gas surge tanks
- Waste compressors
- Gas decay tanks
- Waste gas filters
- Hydrogen recombiners
- Charcoal adsorber beds
- System valves
- Gas analyzers

7.5.1.5.1 Surge and Storage Tanks

The surge and storage tanks serve as a common receiver for excess gas from CVCS, various tanks and other sources of waste gas within the plant.

7.5.1.5.2 Waste Gas Compressors

Redundant 100% capacity compressors provide the means for continuous removal of gases from equipment discharging to the plant vent header and transferring these waste gases to the gas decay tanks for storage at higher pressure. These compressors are usually of the water-sealed centrifugal displacement type. The operation of the compressors is automatically controlled by the radioactive waste gas vent header manifold pressure. A mechanical seal ensures that out leakage from the compressor is negligible.

While one unit is in operation, the other serves as a standby for unusually high flow or failure of the first unit. The system contains provisions to collect and dispose of moisture in the compressor portion of the unit.

A typical compressor is constructed of carbon steel and is 3 feet tall. It occupies a floor space of about 3 feet by 4 feet. The design discharge pressure of the compressor is 110 psig and the design flow rate at 10 psig is 40 cubic feet per minute.

7.5.1.5.3 Gas Decay Tanks

The gas decay tanks are normally welded, carbon steel vessels designed to contain compressed waste gases; i.e., hydrogen, nitrogen, and fission gases. While the tanks are usually designed to provide 30-45 days of storage, they typically store the waste gas for much longer periods.

The quantity of radioactivity contained in each decay tank is limited by Technical Specifications to ensure that, in the event of an uncontrolled release of that tank (such as tank rupture), the resultant total body exposure at the exclusion area boundary does not exceed 500 mrem. This concentration of decay tank activity (equivalent to xenon-133) varies depending on plant location and population density. Technical Specification activity levels for a single decay tank at various plants are:

- Zion 22,000 curies
- Crystal River 47,000 curies
- Sequoyah 50,000 curies
- Calvert Cliffs 53,500 curies

The tanks are released via the plant vent in batch mode at a controlled rate. All such discharges are monitored.

7.5.1.5.4 Waste Gas Filter

The waste gas filter is typically a 1000 scfm HEPA filter/charcoal assembly. It is used to remove particulates from the gaseous effluents as they are discharged.

7.5.1.5.5 Recombiners

Two catalytic hydrogen recombiners are normally provided. Normally one recombiner is in operation. The operation is either continuous or batch mode. The other unit is on standby. The recombiner is designed for a pressure of 150 psig and a flow rate of 50 cfm. The catalytic recombiner accepts a preheated waste gas mixture containing nitrogen, hydrogen and fission 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 waste gas system is as low as practicable, the recombiner operates with a lean oxygen mixture. All the oxygen is reacted. A trace of hydrogen remains at the outlet of the recombiner. The quantity of the gas in the waste gas system is constant, except for small accumulations of fission product gases.

7.5.1.5.6 Charcoal Adsorber Beds

The charcoal adsorbers are cylindrical tanks that hold a bed of adsorption material. The material used for this purpose is generally activated charcoal (freed from adsorbed matter by heating). This material is especially effective because it provides a large surface area with a porous structure. Adsorption occurs at the surface of a solid (activated charcoal) that is in contact with another medium (waste gas). This results in an accumulation of molecules (krypton, xenon, iodine, etc.) from that medium. The activated charcoal only retains these gas molecules for a limited time. It is this adsorption process that allows for the decay of short lived radioisotopes and passes the 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 the BWRs. The holdup time or adsorption resident time of the adsorption system depends on various factors. These include:

- Adsorption material
- Amount of adsorption material
- Temperature
- Flow rate
- Moisture content of gas phase

A lower temperature, flow rate and moisture content of the waste gas results in a higher adsorption resident time.

7.6 COMMON GASEOUS WASTE TECHNOLOGIES SYSTEMS

7.6.1 Particulate Filtration

Particulate material is usually removed by means of High Efficiency Particulate Air Filters (HEPA). HEPA Filters are available in a variety of materials including fiber glass cloth, pleated paper, stainless-steel, and ceramics. The pleated paper filters are most commonly used in U.S. LWRs. HEPA filters are available in a number of physical forms such as

roller type and reusable candle-type filters. Efficiencies of HEPA Filters will vary depending on the chemical and physical characteristics of the gaseous waste stream, but in general, they are very efficient. For example, a HEPA Filter is capable of removing 99.97% of the particulate materials (greater than 0.3 μm diameter) from building ventilation streams.

Prefilters are sometimes used upstream of HEPA Filters to prolong the usefulness of the HEPA Filter. Some of these filters are constructed of ceramic and stainless steel which can be cleaned and reused. Plant workers can identify when filtration units require service by monitoring the pressure differential across these units. A high pressure differential indicates that the filters are becoming blocked. When this occurs the HEPA filter is changed out while the prefilters are cleaned through either a reverse flow process or physical rapping.

7.6.2 Charcoal Adsorption Systems

Charcoal adsorption systems are used to treat the noble gas constituents of the gaseous waste streams. The noble gases are more strongly adsorbed to the charcoal than the lighter gases that carried them (e.g., hydrogen, oxygen, nitrogen). However, the noble gases are not very strongly adsorbed to the charcoal surface. They simply migrate at a slower rate than the carrier gases. As a result, this system only provides sufficient delay to decay some of the short half life gases; it has no affect on the longer lived isotopes such as krypton-85 which passes through the system.

It is possible to further increase the delay time through adjustments in the gaseous waste stream temperature, pressure or humidity. This is accomplished by pre-treating the waste streams before they contact the charcoal beds. The most common pre-treatment systems are comprised of glycol refrigeration units, which lower the temperature, and desiccant dryers, which remove moisture. Removal of moisture from the gaseous waste stream increases the gas adsorption capacity on charcoal.

7.6.3 Iodine Removal

In most facilities, radioiodine is removed through charcoal adsorption systems that are similar to the systems used to delay and decay noble gases. The iodine removal system, like the noble gas system, uses activated charcoal. However, the charcoal in iodine removal systems is also impregnated with metals like silver. The iodine removal system consists of prefilters, HEPA Filters, and iodine absorbers. The iodine absorbers are filled with silver-impregnated activated charcoal or silver impregnated zeolite. Silvered copper mesh has also been used as an alternative. These systems provide higher removal efficiencies for iodine than the normal charcoal adsorption system.

7.6.4 Cryogenic Distillation

Another method for treating the noble gases is physical removal from the gaseous waste stream. This is accomplished by cryogenic distillation. In a cryogenic distillation system, noble gases are condensed out of the waste stream as it passes through a distillation column operated at very low temperature. Success of removal is dependent on the size of the distillation column and the operating temperature. During this process traces of carbon dioxide, moisture, and ozone are removed and the remaining gases are compressed and cooled to a liquid state. The liquid passes to a distillation column at cryogenic temperatures

and the noble gases are separated by fractional distillation. The liquefied noble gases are

then transferred to a gas cylinder for storage and decay. As with the charcoal adsorption system, krypton-85 is not affected by decay and is eventually released.

7.7 AREAS OF CONCERN/TROUBLE SHOOTING

Excessive in-leakage to the system causes an increase in gas volume that can lead to premature discharge of the tanks (e.g., shorter than the system design decay times). More typically, the frequency of release is less often than the design frequency.

7.7.1 Redundancy

The reliability of the gaseous radwaste system is an important design consideration since system failure can result in increased off site radiation levels. Implementing some level of redundancy in individual system components is one method for safeguarding against system failure. However, it is not practical to supply complete redundancy for system operations due to cost considerations for providing redundancy. Such costs are usually measured against system downtime as a result of individual component maintenance. The need for redundant gaseous radwaste subsystems should be based on:

- The type of component failures expected
- The effect of component failure
- The System/component maintenance history
- The cost of providing redundancy
- The cost associated with component outage

Redundancy should be provided when the benefits of increased component availability outweigh the cost.

7.7.2 Activity Build Up/Considerations

Worker exposure is a significant concern when maintaining or removing gaseous radwaste processing equipment from operation. Pre-planning for these activities will contribute to minimizing worker exposures. The potential for exposure during maintenance can be minimized by implementation of:

- Pre-decontamination using water or chemical agents
- Radioactive material removal prior to maintenance
- Allowing time for decay before maintenance
- Use of semi-remote methods (i.e., long handled tools)
- Use of portable shields

7.8 IMPLEMENTATION OF APPENDIX I

Modification to gaseous waste management systems in response to Appendix I include:

- More extensive use of charcoal filtration
- Increased gas decay tank capacity
- More widespread use of systems to eliminate gaseous emissions associated with steam generator blowdown
- Venting of gaseous emissions from mechanical vacuum pump to the condenser

- Special provisions to control steam leakage from steam line valves

7.9 BWR OFF GAS SYSTEM

The purposes of a BWR Off Gas System are:

- Process non-condensable gases from the main condenser
- Minimize and control the release of radioactive noble and activation gases
- Minimize the explosion potential
- Reduce gaseous waste volume
- Remove airborne particulates from gaseous waste steam
- Maintain off-site exposures within Appendix I limits
- Improve response times under normal conditions.

The major noble gases processed by the Off Gas System are shown in Table 7.9-1. Figure 7.9-1 provides a block diagram of the Off Gas System.

Historically, there are three basic types of Off Gas Systems. They are:

- 30-minute holdup system
- Augmented system
- RECHAR (REcombination/CHARcoal)

The RECHAR is the most predominant and is the focus of discussion in this course. The 30 minute holdup systems are no longer in use without supplementation, usually backfitting to RECHAR. The augmented Off Gas System is used on several BWR-4's, but is an exception rather than the rule. Moreover, the RECHAR is standard with BWR-5 and BWR-6 units.

Technically, operation of the gaseous waste treatment system is not required if the Technical Specifications are not exceeded.

However, the Off Gas System should be in operation during plant startup, while at power operation, and during plant shutdown.

7.9.1 Summary of Gas Sources

The BWR Off Gas System processes radioactive gases from:

- Drywell
- Ventilation systems
    - Radwaste Building
    - Reactor Building
    - Turbine Building
- Gland Seal System
- Mechanical Vacuum Pump
- SJAE Discharge

7.9.2 System Description

The Main Condenser is the primary source of process gases. It enters the Off Gas System via the steam air ejectors.

The Off Gas System removes noncondensable gases from the main condenser via steam jet air ejectors, which provide the dilution and motive force for the remainder of the gaseous system. From the steam jet air ejector discharge, the gaseous mixture is first processed by a catalytic recombiner to reduce the hydrogen and oxygen concentration. The remaining mixture is then retained in a holdup tank to allow the short-lived fission gases and their particulate progeny to decay. The Off Gas Stream then passes through a high efficiency filter to remove particulates and then to charcoal absorbers to retard passage of xenon and krypton. The processed off-gas is then monitored for release and discharged to the Plant Exhaust Ventilation System.

The Off Gas System (Figure 7.9-2) takes suction through two large lines from either end of the main condenser depending on the circulating water flow. However, suction is always from the "cold" end. This removes discharge steam, air and non-condensable gases from the main condenser via the steam jet air ejectors (SJAE).

Inputs to the gaseous source term include:

- SJAE
- Mechanical Vacuum Pump
- Turbine Gland Seal (only older plants using radioactive steam)
- Containment Purge
- Reactor/Turbine/Radwaste Buildings Ventilation

The air ejector off gases consist of:

- Radiolytic hydrogen
- Radiolytic oxygen
- Air in-leakage
- Water vapor
- Radioactive noble gases
- Activated nitrogen and oxygen (nitrogen-13, nitrogen-16, and oxygen-19)

The normal flow rate is between 100 and 200 scfm and is nearly 50% hydrogen, 25% oxygen, and 15% water vapor, the bulk of the remainder and the most variable quantity is air in-leakage. The air in-leakage design rate is 30 scfm. However, experience shows that the actual leakage rates are 6 scfm or less.

While the activity of noble gases is significant (50 - 60 μCi/sec), their volume is very small. The radioactivity contribution of nitrogen-13, nitrogen-16, and oxygen-19 is not significant because they have very short half-lives. Therefore, the objective is to reduce the volumes of the other components and thereby provide ample holdup time for radioactive decay of the noble gases.

The non-condensable off gas is drawn from the main condenser through the steam air ejectors. The first stage SJAE takes suction from the main condenser and exhausts a gaseous mixture to the intercondenser and exhausts the gaseous mixture of the Off Gas System.

The last stage of the air ejector is non-condensing and supplies the motive force to overcome pressure losses downstream and the steam to dilute the concentration of hydrogen.

After passing through the air ejector, the stripped gases are sent to a recombiner that consists of preheater, catalyst, and condensing sections. The preheater section heats the gases for efficient catalytic recombiner operation and ensures the absence of water. This affords a substantial reduction in volume because these are normally the major contributors to off gas volume.

This recombination also ensure the hydrogen concentration is <4% by volume and precludes an explosive gas mixture.

The water vapor and steam are condensed and drained. After recombination, the mixture is cooled in the off gas condensers by the flow of condensate through the heat exchanger tubes. This strips the condensable by condensation and reduces the volume. The remaining condensable (principally air with traces of fission gases) are cooled in the cooler condenser and then passed through a desiccant dryer. The dryer reduces the dew point. The gas leaving the dryer is chilled before it enters the charcoal adsorption vault.

Decay of the noble fission gases and formation of the major fraction of particulate radioactive progeny occurs during this holdup.

Charcoal adsorption beds, operating in a refrigerated vault, selectively adsorb and delay xenons and kryptons from the gas. This permits time for decay. After the delay, the gas is passed through a high efficiency air particulate filter and discharged to the environment via the ventilation exhaust.

A number of plants do not use chilled charcoal units. In such cases, the demoisturized air is reheated to provide the desired humidity control prior to filtration by high efficiency filters and charcoal absorbers.

The charcoal retards the noble gases to enable additional decay in the enclosed system. After leaving the charcoal absorbers, the gaseous waste stream is refiltered and released via a high stack to the atmosphere.

The delay time provided in the 30-minute holdup pipe and the charcoal bed results in decay of a very large fraction of the radioactive noble gases. Only krypton-85 with a 10 year half-life is present without substantial reduction and it is only a small fraction of the original composition. Furthermore, the particulate progeny are removed by filtration following the 30-minute holdup or are retained on the charcoal. The final filtration of the charcoal absorber effluent precludes escape of charcoal fines; therefore, particulate releases are negligible. Although the radioiodine input into the Off Gas System is small because of its retention by the reactor water and condensate, the charcoal is effective in absorbing it and eliminating its release in plant airborne effluent.

Radiation monitors at the air ejector discharge continually monitor radioactivity released from the reactor. This, in effect, provides continuous monitoring of:

- Fuel leakage
- Input to charcoal filters
- Release rate from the charcoal units
- Release rate to the environs

High radiation at the air ejector results in an alarm to warn of high radioactivity in the off gas. A radiation monitor at the treatment plant discharge provides a trip signal to prevent treated gases with an unacceptable activity from entering the unit vent. The equipment is frequently monitored and operated from the Control Room.

In the basic RECHAR System, the charcoal absorbers are operated at ambient room temperature, so that even during shutdown the radioactive gases in the absorbers are subject to the same holdup time as during normal operation despite normal flow. Some units are chilled or cooled to provide greater retention times.

The air ejector Off Gas System operates at a low pressure (<6 psig), so the differential pressure does not result in significant leakage. To further preclude leakage the system is welded wherever practicable and bellows seal valve steam, or equivalent, are used.

Continuous radiation monitoring provides indication of radioactive release from the Off Gas System. The off gas post treatment effluent radiation monitor isolates the system upon high radioactivity and prevents discharge of unacceptably high activity.

The mechanical vacuum pumps are used for plant startup. They take suction on the main condenser and discharge the noncondensable gases to the turbine building exhaust duct. After a vacuum of about 25 inches of mercury is established by these pumps and sufficient steam pressure is available, the SJAEs are placed in service.

7.9.3 Off Gas System Components

The typical BWR Off Gas System consists of:

- Main condenser[*]
- Steam Jet Air Ejector Assembly (SJAE)
- Mechanical vacuum pumps
- Off gas preheater
- Catalytic recombiner
- Off gas condenser
- Water separator or gas dryer
- Hydrogen analyzers
- 30-minute holdup pipe
- Cooling condenser
- Moisture separator
- Electric reheaters

- Prefilter
- Charcoal absorbers
- After filters
- Ventilation stack

* Not integral part of system; functional component only.

Example Off Gas System component operating characteristics are provided in Table 7.9-2.

7.9.4 Steam Jet Air Ejector Assembly

Noncondensable gases are removed from the main condenser by steam jet air ejectors (SJAE) that are supplied steam from the Main Steam or Auxiliary Boiler.

The SJAE is a two stage venturi type steam air ejector. Some sources also consider the intercondenser a second stage and describe it as a three stage unit. The first stage is equipped with an intercondenser that minimizes water droplet carryover, limiting the amount of moisture that enters the Off Gas System. The second stage is noncondensing. It dilutes the concentration of hydrogen gas to <4% by volume and provides the driving force for process flow through the Off Gas System.

The SJAE suction is via air-operated gate valves with accumulators, which are located in the feedwater area near the main condenser. Suction is automatically routed from the cold end of the main condenser. This arrangement is shown in Figure 7.9-3.

Each of the 100% capacity SJAE use a high velocity jet of steam to create low pressure at the inlet for the removal of noncondensable gases from the main condenser shells. The main steam, reduced to 12 psig, is supplied through a strainer to each of the SJAE nozzles. The nozzle accelerates the steam to a high velocity that passes through the diffuser throat as it begins to expand. Gas molecules present in the suction chamber become entrained in the steam and are carried by the steam.

The first stage utilizes the intercondenser with the steam providing a driving flow from the turbine throttle through a pressure regulating valve. The second stage utilizes the after condenser, but has the same driving flow as the first stage. Steam is supplied to the third stage of the SJAE (booster air ejector) from the existing steam supply line that supplies the first and second stage units. The steam supply line also provides steam to the discharge of each booster air ejector through a restricting orifice. This stage provides dilution flow to maintain the hydrogen gas concentration in the off gas below 4%. The third stage provides the system driving force. Hydrogen is a significant portion of the noncondensable gases.

First stage driving steam is condensed by the condensate and feedwater system through tubes in the intercondenser. This action also provides some preheating of the condensate. Condensate is allowed to drain back to the main condenser shell through a loop seal that prevents noncondensable gases from returning to the condenser. The intercondenser normally operates with a vacuum of about 20 inches of mercury.

Each SJAE set has only one final stage jet, which takes suction from the intercondenser for that set. This jet stage removes non-condensable gases for the intercondenser and discharges them along with its driving steam to the remainder of the Off Gas System.

An air purge supply with a capacity equal to the minimum design condenser air in-leakage flow is provided upstream of the recombiner. When the condenser air in-leakage falls below the design minimum of 6 scfm and the hydrogen concentration exceeds 1%, the air purge is initiated to provide sufficient hydrogen dilution.

Each steam supply has an individual pressure control valve with isolation and bypass capability. The line has a local pressure controller, indicator, and a low pressure switch that produces an alarm and isolates the off gas suction valves on decreasing pressure. This interlock can be bypassed on system startup by turning the off gas bypass selector switch to a bypass position.

Off gas suctions to the booster air ejectors are tied together between the isolation valves from each steam jet air ejector discharge line. This provides the flexibility to select either booster jet with either set of air ejectors and route SJAE second stage flow directly to the 30-minute holdup pipe, final filters, and vent.

7.9.5 Mechanical Vacuum Pumps

The mechanical vacuum pumps are used to remove air and noncondensables from the main condenser during startup when steam pressure is less than 260 psig. The two pumps are vane-type centrifugal pumps rated at 2350 scfm. Each pump is driven by a 100 hp motor.

7.9.6 Off Gas Preheater

The off gas preheater superheats the steam-gas mixture exiting via the SJAE to 350^{o} F. This ensures:

- Appropriate temperature for efficient catalytic recombiner operation
- Absence of water

Water would poison the recombiner catalyst.

The off gas preheater is a U-tube heat exchanger with a single pass shell for the off gas and multi-pass tubes for the steam side.

Steam is used for heating rather than electricity because hydrogen is present and could be ignited by an electrical spark once water is condensed form the off gas stream. The steam from the turbine throttle enters through a pressure regulator at about 250 psig. The unit is designed to limit temperature under 410^{o} F in the event that flow of off gas is lost. The nuclear steam enters the tube side of the preheater and heats the gaseous mixture on the shell side to around 350^{o} F at the preheater exit. Steam is supplied from the same line that supplies the booster air ejector with steam. Individual pressure control valves maintain proper pressure.

After it passes through the U-tubes in the preheater, the steam is exhausted though a solenoid operated isolation valve into a high pressure trap to the main turbine condenser. The isolation valve can be operated from the Control Room. The inlet to the trip also has a solenoid operated isolation valve and a cross-tie line to the other recombiner loop.

The tube side of the preheater is equipped with double valved vents and drains. These discharge though a funnel and loop seal drain pot to the turbine building equipment drain sump. The tube side is protected from over pressure by a relief valve, which relieves to the main condenser.

7.9.7 Catalytic Recombiner

The catalytic recombiner receives the gaseous mixture containing the radioactive fission gases, radiolytic hydrogen and oxygen produced from the dissociation of water, and the dilution steam. It removes the majority of hydrogen and oxygen gases by recombining than into pure water vapor, which is condensed. This reduces the volume of gas to be processed and limits the hydrogen to safe concentrations. The purpose of the recombiner is combine sufficient hydrogen and oxygen so that the final hydrogen concentration is <1% by volume.

The catalytic recombiner contains a platinum catalyst to promote the recombination of radiolytic hydrogen and oxygen in the Off Gas System. The catalyst causes the hydrogen to burn slowly rather than explode. The amount of hydrogen and oxygen in the process stream varies with reactor power. About 0.03 to 0.055 scfm of hydrogen and oxygen are produced for each thermal megawatt of reactor power that is produced.

The preheated off gas mixture flows to the catalytic recombiner. Inlet temperature is monitored by a temperature indicator and low temperature alarm with readout in the Control Room. Each recombiner has external heaters to maintain the standby unit temperature when it is not in use; therefore, it is ready for service.

Off gas enters the recombiner at 350^{o} F and exits at 850^{o} F. During normal operation, the process stream leaving the catalyst contains <0.1% hydrogen by volume. Maximum permissible hydrogen levels under any conditions do not exceed 1.0% by volume.

The catalytic element is replaceable and is instrumented to provide temperature information in the Control Room. The recombiner converts the hydrogen and oxygen into water vapor, thereby reducing both the off gas volume and any potential for uncontrolled hydrogen ignition.

Not only water, but also freon, oils, and halogens poison the catalyst and must be precluded from the off gas.

7.9.8 Off Gas Condenser

The Off Gas Condenser is normally located in the recombiner room and cools the superheated steam and condenses the water vapor from the outlet of the recombiner.

It is also a U-tube heat exchanger with a single pass shell and multi-pass tubes. It differs in function from the preheater in that the off gas is on the tube side and the steam/air is on the shell side. Therefore, it removes rather than adds heat to the off gas stream.

Cooling water from condenser hotwell down-stream of the gland seal condensers passes through the U-tubes in the heat exchanger and is returned to the condensate system at the inlet to the condensate demineralizers.

The gaseous mixture passing through the shell side of the condenser is cooled and the resultant water drains through a funnel and loop seal to the main condenser by gravity and vacuum. This process is designed to reduce the off gas temperature from 850^{o} F to <140^{o} F.

7.9.9 Water Separator

The moisture separator removes entrained moisture from the Off Gas Condenser effluent. The water separator has no moving parts and is essentially a vessel containing a stainless steel demister assembly. The moisture is collected by the demister and dropped to the bottom of the vessel through a drain in a loop seal and to the inlet of the off gas condenser.

7.9.10 Hydrogen Analyzers

One of two hydrogen analyzers continuously monitors hydrogen in the off gas exiting the water separator during operations. Each analyzer provides separate and independent sample collection, analysis and monitoring of hydrogen.

7.9.11 Holdup Volume

The holdup volume is a large pipe where short-lived radionuclides (principally nitrogen-13, nitrogen-16, oxygen-19 and certain isotopes of xenon and krypton) decay either to stable forms or to particulate daughter products.

Off gas for the Off Gas Condenser flows into a length of pipe sized to provide turbulent flow at normal flow rates. The holdup time in early BWRs was thirty minutes.

The thirty-minute holdup pipe is an under-ground 36" diameter pipe that is 965 feet long. Its purpose is to holdup the short half-life xenons and kryptons long enough to effect substantial reduction in the total activity and to complete formation of particulate progeny prior to release to the environs.

The off gas mixture is routed through a long pipe to provide sufficient transient time to permit decay of the shorter-lived radionuclides. The 30-minute holdup time assumes no recombination of radiolytic gases. The mixture traverse time increases to more than four hours as a result of removal of hydrogen and oxygen in the catalytic recombiner. Under conditions of normal recombiner flow, if there is no substantial air in-leakage to the condenser off gas, the actual holdup time is often 6 hours.

This delay allows the bulk of the short-lived gaseous nuclides to decay to particulates that are filtered from the stream. Since moisture condenses inside the holdup pipe, it has a loop-seal drain to the radwaste system.

7.9.12 Cooler Condenser

The function of the cooler condenser is to reduce the gas-steam temperature to about 40^{o} F. This means that if the gas is saturated at this temperature, it will have a relative humidity of about 33% (or less than 1% of the gas) at ambient temperature of the charcoal system

(77^o F). This is important because the charcoal efficiency is a function of the processing stream moisture content.

It is also a U-tube heat exchanger with a single pass shell and multi-pass tube. In this case, off gas now consisting primarily of air/water vapor passes through the shell and is cooled by a water/ ethylene glycol mixture. The glycol is in turn cooled by a freon refrigeration unit located in the filter building.

The off gas passes through the shell side of the cooling condenser through a remote manual isolation valve and makes several passes over the tubes. This chills the gas leaving the condenser to about 40^o F (in some facilities this temperature is up to 45^o F).

7.9.13 Moisture Separator

The filter building moisture separator is similar to the water separator in the recombiner room except for its piping size and operating flow rate. This difference reflects its purpose to eliminate excess moisture rather than bulk removal of water vapor.

7.9.14 Electric Reheaters/Dryers

The Off Gas Reheater is basically a wrapping of a number of high-wattage strip heaters around a section of piping between the moisture separator and the pre-filter. It serves to reheat the chilled demoisturized air to reduce the relative humidity of the off gas to suitable levels for filtering. In some plants that use chilled temperature charcoal absorbers, the reheater before the prefilters is not used. The RECHAR operated at lower temperature utilizes coolers and reheaters to dry the stream before it enters the charcoal beds.

7.9.15 Prefilter

Two parallel filter assemblies are installed to remove particulates formed from decay of short-lived fission gases during system holdup. The prefilters minimize the contamination downstream of components and extend the life of the charcoal beds.
The prefilter is a 99.97% efficiency HEPA filter to remove any particulates in the remaining process gas.

7.9.16 Gas Dryers

In some plants gas dryers are used upstream of the charcoal absorbers to remove moisture from the process stream. The lower the moisture level in the process stream leaving this equipment the better the charcoal absorbers perform.

A gas dryer/regeneration skid consists of four components:

- Desiccant dryer vessel
- Regeneration heater
- Regeneration blower
- Regeneration dryer chiller

There are two completely redundant dryer/regenerator trains on the same skid. Each of the two desiccant vessels is capable of drying the process stream at a flow of 30 scfm to a -90^o F dew point for a minimum of 3 days before requiring regeneration. The dryers can be

regenerated in 12 hours. These dryers are not normally used at plants where the RECHAR system is operated at ambient temperature.

7.9.17 Gas Cooler

The gas cooler is provided in the charcoal absorber vault to cool the process gas from 78^{o} F to 0^{o} F before it enters the charcoal absorbers. A vault refrigeration fan circulates air in the vault over the finned surface of the process piping.

7.9.18 Charcoal Absorbers

The charcoal beds contain activated carbon in granular charcoal form. The charcoal retards the progress of xenon and krypton in the off gas stream, allowing decay of several noble gases to particulate daughter products, which can be removed by filtration.

The filtered flow from the prefilter passes through a bank of vessels containing charcoal. Temporary adsorption of the noble gases on the charcoal provides additional retardation, thus decay, time prior to discharge via the ventilation stack. The charcoal absorber subsystem is shown in Figure 7.9-4.

The charcoal absorber vessels are large (typically about 4 feet in diameter and over 20 feet long). Each contains several tons of granulated charcoal.

As suggested by the number of components in the off-gas stream treatment prior to the charcoal absorber vessels, it is extremely important to prevent "wetting" or "poisoning" of the charcoal beds if they are to be effective. Wetting degrades the adsorption ability of the charcoal. Poisoning differs from wetting in that it results from coating of the resin by contaminants such as oil and can cause localized thermal hot spots that could lead to combustion in the bed.

The vessels are maintained under constant temperature (typically about 77^{o} F).

7.9.19 Charcoal Absorbers (Chilled)

Some facilities operate with chilled vessels to enhance their adsorption times or reduce the physical size of this portion of the off gas system.

Eight charcoal absorber vessels, in two parallel trains of four vessels each, are housed inside a refrigerated vault. The charcoal absorbers operate at a nominal 0^{o} F. Each vessel contains activated charcoal granules. The off gas flow enters the bottom of each absorber through a distribution ring. The flow is in an upward direction to minimize the potential for channeling. The outlet distribution ring at the top of each vessel directs the flow to the outlet piping.

Activated charcoal has very large surface area with many small openings. It has a particular affinity for xenon and krypton. These elements are attracted to the charcoal surface and adsorb there.

As the off gas flow passes through the charcoal bed, the air from condenser in-leakage acts as a carrier gas for these fission gases. An atom of xenon adsorbs on a surface site and remains there until its random motion produces sufficient energy to break the weak

electrostatic bond with the charcoal. The released atom is carried through the charcoal bed until it is again adsorbed at another site. This process repeats as the xenon passes through the charcoal bed. By maintaining the charcoal at low temperature, the individual atoms have less kinetic energy and have a longer residence time at any given site.

The time required for an atom to pass through the charcoal bed is referred to as holdup time. Holdup time is calculated by:

$$T = \frac{K_a \; M}{F}$$

Where:

- T = holdup time (min)
- F = gas flow rate (cm^3/min
- M = mass of charcoal (g)
- K_a = dynamic adsorption coefficient (cm^3 STP/g).

The charcoal in the absorber bed is designed to produce K_a values of 1170 and 59.7 cm^3/g for xenon and krypton respectively. Given the size of the absorbers and a flow rate of 30 scfm (0.85 m^3/min), the holdup time for xenon is 42 days and for krypton it is 46 hours. This is sufficient for most radionuclides to decay and generate about 60 BTU/hr of decay heat. When the gases decay, they form particulate compounds that become permanently lodged in the charcoal bed. The great majority of gaseous off gas activity is captured in the absorber charcoal. Radioiodine input into the off gas system is small by virtue of its retention in the reactor water and condensate. The iodine remaining is essentially removed by adsorption in the charcoal. This is supported by the fact that charcoal filters remove 99.9% of the iodine in 2 inches of charcoal, whereas the system has approximately 76 feet of charcoal in the flow path.

Removable plugs of charcoal granules allow periodic monitoring of charcoal bed activity. If the activity is too great, then the charcoal must be replaced.

7.9.20 Charcoal Vault

The Off Gas Charcoal Vault is maintained at 0^{o} F by refrigeration units located external to the vault.

7.9.21 After Filters

The after filters are HEPA filters located near the ventilation stack that receive flow from the charcoal absorber vessels and provide for removal of particulates formed during the off gas transit through the charcoal and to ensure that charcoal fines are not released. This is the final processing step prior to release to the environs via a tall ventilation stack. The stack provides an elevated release for greater dispersion of remaining fission gases.

7.9.22 BWR Differences

Earlier BWR Off Gas Systems consisted of two SJAEs, a 30-minute holdup volume, HEPA Filters, and an off gas isolation valve. To reduce hydrogen concentrations and off gas release rates, the original systems are backfitted with a RECHAR System.

The low temperature system is generally more efficient than the ambient temperature system because of an increase in the dynamic adsorption coefficient.
At least one BWR uses a cryogenic distillate system in lieu of RECHAR.

7.9.23 System Interrelations

The RECHAR System is interrelated with:

- Main Steam System
- Radwaste sparging pump
- Pressurized Drain System
- Off Gas Filter Building HVAC System
- Valve Pressurization System
- Radiation Monitoring System

The Main Steam System provides the driving force to the SJAE. The radwaste sparging pump provides oil-free air for system purge prior to startup. The Pressurized Drain System tanks receive off gas condensate. The Off Gas Filter Building HVAC System provides all outside air, maintains environmental control, and filters all exhaust to the stack for the Off Gas Filter Building. The recombiner room ventilation system serves the same function for that building. The filter building sump pumps eliminate water from the off gas filter building floor sumps. The valve pressurization system ensures that the Off Gas System is leak tight.

7.10 AIR FILTERS

7.10.1 Air Filtration

The theory for air filtration is currently inadequate to fully describe the processes, but approximation can be calculated and empirical estimates of trends can be determined.

For general dust removal fibrous filters are typically used. The fibers can be either natural (wool, cotton, cellulose) or synthetic (glass, organic polymers). Fiber layers are extremely porous consisting of only 1 to 10% fiber by volume. In general the mean interfiber distances are between 2 and 9 fiber diameters. Therefore, the filter does not act as a sieve as commonly believed. Air cleaning occurs as particles in the gas stream pass close enough to the fiber to reach it and be held there by adhesive forces. To improve air filtration of high air volumes, the fibers are woven or felted into a fabric. The two most important characteristics of the fiber filters are separation and adhesion. In this case filtration occurs at the filter surface. Typically, a filter cake is formed, which acts as a filter medium itself.

Fibrous filters are not mechanical sieves; their efficiency depends on impingement and adhesion of particles on individual fibers. Filter media should have a low resistance to air flow and a high porosity to prevent clogging.

Inter-fiber distances should be largely compared to particle size and fiber diameter. The fiber size should be smaller than the smallest particle size of importance in the air stream to be filtered. The use of finer fibers increases the total deposition area of the filter. This provides large surfaces for the electrostatic charges and other adhesive forces to hold removed particles. The fibers lie in regular layers perpendicular to the air stream flow.

7.10.2 HEPA Filters

Design information for high-efficiency filter systems is reliable for a limited set of conditions and specific filter media. The ability to predict performance of filters is limited to specific ranges for velocity and pressure, size of particles and fibers, their chemical composition and distribution of electrostatic charges.

The principal criteria for measuring performance of fibrous filters are its removal efficiency and pressure drop.

It is generally assumed that if a particle touches a filter fiber during passage through the filter, Van der Waal forces cause it to adhere. The impact between a particle and a fiber is non-elastic so there is no recoil of the particle and the particles are not readily blown loose. Small particle adherence to the fiber approaches 100%, but high adhesion efficiency is not maintained when the particles are larger than 5 microns. Moisture in the air stream increases retention of larger particles.

HEPA Filters are used in gaseous streams to remove fine particulates. They are used primarily for submicron particle removal and are not intended as course dirt collectors. They have low dust capacity and plug rapidly when exposed to high concentrations of dust, lint, or smoke. The manufacturer tests the filters to requirements for percent removal (~ 99.97% removal of 0.3 μm particles).

In gaseous waste applications, an important function of filters is to collect radioactive particles formed when a gaseous parent nuclide decays to a solid radioactive daughter.

For maximum effectiveness, HEPA Filters are placed where particulate concentrations are highest.

HEPA Filters are tested in place with dioctylpthalate (DOP) to verify that the filters are not punctured during installation and to ensure that a good seal is obtained with the filter housing.

Since filters are very efficient at removing particulates with associated radioactivity and handle very large volumes of air, they accumulate sufficient radioactivity to produce radiation exposure during use and become a source of solid radwaste after use.

7.10.3 Principal Mechanisms

In the flow around a fiber several mechanisms contribute to particle deposition. Filtration depends on:

- Inertial impaction
- Interception
- Brownian diffusion
- Electrostatic attraction
- Gravitational settlement

Since filters operate in the laminar flow region, they trap particles primarily by a combination of inertial impaction, interception and diffusion. Gravitational sedimentation is usually insignificant. Gases and vapors are not removed efficiently by fibrous filters.

These mechanisms combine algebraically to determine the overall efficiency of the filter system under specific operating conditions for a specific air stream. A number of factors influence the fraction of particles of a given size that penetrate the filter. These include fiber diameter, medium packing density, air velocity, particle density, electrical forces, etc. The particle size for maximum penetration varies with these factors but is generally in the range of 0.1 to 0.3 microns. Particles larger than 0.3 micron penetrate the fiber less easily as the particle size increases. On the other hand, below the 0.3 micron size, increased Brownian movement reverses this trend. The maximum penetration size shifts toward the smaller size as air velocity increases and reduces the relative importance of Brownian diffusion.

7.10.3.1 Inertial Impaction

Particles tend to follow the air streamline; however, if the air is deflected around an obstacle, the particle is unable to follow the stream line and inertia tends to carry it in a straight line. If the particle deviates from the air stream and crosses the streamlines, it can impact on obstructions in the path such as a filter fiber. This will remove the particle from the air stream. Inertial impaction is controlling in the region of high air stream velocities. In general, this leads to increased removal efficiency with increased velocity in this region because particle momentum is more likely to carry it across the streamline if the particle is traveling faster.

It is assumed that every particle touching a fiber sticks. This is not the case for particles >5 μm in diameter. The efficiency for collection by inertial impaction approaches asymptotically with increasing particle diameter (at a Reynolds Number $\leq$0.1, inertial impaction is greater than interception).

7.10.3.2 Interception

Particles are not point masses. They have a finite size, so particles can touch the fiber surfaces as they pass near the fiber (1/2 the particle diameter). The effect of interception increases as the particle diameter increases.

When a particle in the air streamline moves around a fiber, if it passes within one particle radius of the fiber, it is intercepted. It does not depend on specific forces but rather results from a boundary condition. Interception appears to be relatively independent of air stream velocity. In the intermediate air velocity region, where it is the dominant removal mechanism, removal efficiency is independent of velocity. Interception increases with particle size.

7.10.3.3 Brownian Diffusion

This type of diffusion is the result of Brownian movement or motion, which is readily observed by looking at dust in the air in an intense beam of sunlight.

In this process, a small particle in air repeatedly collides with the gas molecules and exhibits random motion from the periodic collisions. This random motion causes a particle to deviate from the streamline with which it is originally associated and come in contact with a fiber. The effective size of the particle appears to increase because of the random motion along its flight path.

As a result of intermolecular collision in the gas, small particles tend to zigzag about their statistical mean path (called Brownian movement). This leads to deposition of particles on the fiber. Brownian movement is a significant removal mechanism only for particles smaller than 0.5 µm; however, Brownian movement is more pronounced as the particle size decreases. It is dominant at low air velocities and for particles smaller than 0.5 µm. In this region, collection efficiency decreases with increased air velocities.

Small particles can reach the deep lung when inhaled; therefore, from a radiation protection perspective, they are more important than suggested by their fraction of airborne particles in an air stream.

7.10.3.4 Electrostatic Attraction

Either the particle or a fiber, or both, can have an electrical charge that results in attractive or repulsive forces. The resultant electrical force(s) affect the particle motion and leads to its attraction to the fiber. If both are charged, Coulombic forces operate. When only one is charged image forces operate; i.e., the particle or fiber appears larger than its actual size because of the space charge surrounding it.

The charge in natural aerosols is relatively small and electrostatic removal is important only for particles with a diameter <1 µm at low velocities. Nevertheless, one only has to observe the collection of household dusts on fan blades or other moving surfaces to recognize it is not negligible when considering large volumes of air passing surfaces. Electrical forces occur when either the particles or the fiber have an electrostatic charge or when an external electrostatic field is imposed on the filter. The former normally has more application in removal of radioactive particles from the air in nuclear facilities.

7.10.3.5 Gravitational Settlement

Gravitational settling requires particles with aerodynamic diameters >1µm. Such particles can develop from agglomeration, surface condensation, and evaporative processes, or in high particle density atmosphere by coagulation. The chemical form of an uncharged particle is not important except for solubility properties.

Spherical particles <10 µm in diameter can remain airborne for long periods. Particles >10 µm can settle quickly, but gravitational settlement is a very inefficient means of removing particles <50 - 100 µm. Even the "roughest" filter is very efficient in removing particles >10 µm from an air stream, thus, gravitational settling is not an important consideration in the cleaning of normal atmosphere.

7.10.4 Interference Effect

In a fiber layer, fibers influence each other because they change flow relationships. A mixture of course and fine fibers tends to work together best. For a particular particle size; however, in most practical cases, the fibers are the same size and the particle size is distributed. In most filters, the fibers lie in regular layers of successive fibers that are perpendicular to the gas flow. Particles are evenly distributed throughout the gas before each filter; therefore, the conditions for particle deposition are the same for all fibers. As time passes, the deposited particles form small chains, which also become collecting surfaces. This collection of deposited particles also filters the air stream changing the filter characteristics and overall performance.

7.10.5 Particle Adhesion

It is assumed that particles touching the fiber surfaces adhere to the fiber and are not re-entrained into the gas stream. The impact between particles and fibers is non-elastic, so there is no recoil of the particle. Furthermore, particles are not blown off the fiber. However, particles >5 µm exhibit inadequate adhesion (some loss occurs for particles <1 µm).

The deposition and adhesion of particles on fibers can be considered an agglomeration process. The cohesion of agglomerates is affected by:

- Attractive forces between solids (valence forces, Van der Waals forces, electrostatic forces, double layer forces)
- Solid bridge (sintering chemical reaction, fusion, hardened binders, crystallization of dissolved materials on drying)
- Adhesive forces in immoveable binders (Viscous binders, adhesives)
- Capillary forces on mobile liquid surfaces (liquid bridges, capillary forces)

Of these only three are important to the adhesion of particles in fibers. They are:

- Van der Waals Forces
- Electrostatic forces as a result of excess charging
- Capillary force in a liquid bridge

The Van der Waals Forces are the most important. These are weak attractive forces between neutral atoms and molecules arising from polarization induced by the presence of other particles. These forces obtain their importance because they act over relatively large distances.

However, the agglomeration and cohesion of particles in the environs and on filters are also important because they affect particle size and stability, which in turn, influence collection efficiency, particle transport and gravitational settling along the air stream.

Table 7.1-1: PWR Gaseous Source Terms Prior to Treatment

	Coolant Conc's μCi/g		Generation Rate, Ci/year per Reactor					
Radionuclide	Primary Coolant	Secondary Coolant	Gas Stripping Shutdown	Gas Stripping Continuous	Building Reactor	Ventilation Auxiliary	Air Ejector Exhaust	Total
Kr-85m	1.9E-1	4.0E-8	*	*	2.1E+1	4.0	2.0	2.7E+1
Kr-85	8.1E-1	1.7E-7	4.1E+2	1.6E+3	6.1E+2	1.8E-1	8.0E+1	2.6E+1
Kr-87	1.6E-1	3.1E-8	*	*	6.0	3.0	2.0	1.1E+1
Kr-88	3.1E-1	6.5E-8	*	*	2.3E+1	7.0	3.0	3.3E+1
Xe-131m	8.8	1.8E-6	1.3E+2	2.3E+2	5.9E+3	1.9E+2	8.6E+1	6.5E+3
Xe-133m	2.0E-1	4.3E-8	*	*	1.0E+2	4.0	2.0	1.1E+2
Xe-133	1.2E+1	2.5E-6	2.0	2.0	7.3E+1	2.5E+2	1.2E+2	7.7E+3
Xe-135m	1.1E-1	2.3E-8	*	*	*	2.0E+2	1.0	3.0
Xe-135	1.2	2.6E-7	*	*	2.4E+2	2.5E+1	1.2E+1	2.8E+2
Xe-137	2.4E-2	4 9E-9	*	*	*	*	*	*
Xe-138	1.2E-1	2.5E-8	*	*	*	3.0	1.0	4.0

Total: 1.7E+4

* Less than 1.0 Ci/year

Radioactive Waste Technology. A. A. Moghissi, H. W. Godbee, S. A. Hobart. The American Society of Mechanical Engineers, New York, NY. 1986.

Table 7.1-2: Radioactive Particulate Releases from PWR's

Release Rates, Ci/year per reactor					
Radionuclide	**Waste Gas Processing System**	**Reactor Building Building Ventilation**	**Auxiliary Building Ventilation**	**Fuel Handling Building Ventilation**	**Total**
Cr-51	1.4E -7	9.2E - 5	3.2E - 6	1.8E - 6	9.7E - 5
Mn-54	2.5E - 8	5.3E - 5	8.8E - 7	4.0E - 6	5.8E - 5
Co-57	0	8.2E - 6	0	0	8.2E - 6
Co-58	1.0E - 7	3.7E - 4	5.4E - 6	3.7E - 5	4.1E - 4
Co-60	1.7E - 7	3.8E - 5	3.9E - 6	1.7E - 5	5.9E - 5
Fe-59	1.8E - 8	2.7E - 5	3.1E - 7	0	2.7E - 5
Sr-89	4 4E - 7	1.3E - 4	7.5E - 6	2.1E - 5	1.6E - 4
Sr-90	1.7E - 7	5.2E - 5	2.9E - 6	8.0E - 6	6.3E - 5
Zb-95	3.2E - 8	9.1E - 6	0	0	9.1E - 6
Nb-95	3.7E - 8	1.8E - 5	2.9E - 7	3.2E - 5	5.0E - 5
Ru-105	3.2E - 8	1.6E - 5	3.2E - 7	9.8E - 7	1.7E - 5
Ru-106	2.7E - 8	0	6.0E - 8	6.9E - 7	7.8E - 7
Sb-125	0	0	0	1.7E - 6	1.7E - 6
Cs-134	3.9E - 7	3.5E - 5	4.8E - 6	7.4E - 6	4.8E - 5
Cs-136	5.3E - 8	3.2E - 5	4.8E - 7	0	3.3E - 5
Cs-137	1.9E - 6	7.4E - 5	1.2E - 5	1.9E - 5	1.1E - 4
Cs-138	2.3E - 7	0	2.7E - 6	0	2.9E - 6
Ce-144	2.2E - 8	1.3E - 5	3.6E - 7	0	1.3E - 5
					Total: 1.2E - 3

Release rate assumed to be independent of plant size.

Table 7.1-3: BWR Gaseous and Airborne Particulate Source Terms Prior to Treatment

	Generation Rates, Ci/year per reactor						
Radionuclide	Containment Building	Auxiliary Building	Turbine Building	Radwaste Building	Gland Seal	Mechanical Vacuum Pump	Total
Kr-85m	1	3	25	*	*	*	29
Kr-87	*	2	*	61	*	*	63
Kr-88	1	3	91	*	*	*	95
Kr-89	*	2	580	29	*	*	611
Xe-133	27	83	150	220	*	1300	1780
Xe-135m	15	45	400	530	*	*	990
Xe-135	33	94	330	280	*	500	1237
Xe-135	45	135	1000	83	*	*	1263
Xe-137	2	6	1000	2	*	*	1010
I-131	1.1E-1	2.1E-3	0.11	0.11	*	0.082	0.31
I-133	1.5E-2	2.9E-1	1.6	0.15	*	0.92	3.0
Cr-51	2E-4	9E-4	9E-4	7E-4	0	6E-6	3E-3
Mn-54	4E-4	1E-3	6E-4	4E-3	0	0	6E-3
Fe-59	9E-5	3E-4	1E-4	3E-4	0	0	8E-4
Co-58	1E-4	2E-4	1E-1	2E-4	0	0	2E-1
Co-60	1E-1	4E-1	1E-3	7E-3	0	6E-6	1E-2
Zn-65	1E-3	4E-3	6E-3	3E-4	0	3E-7	1E-2
Sr-89	3E-5	2E-5	6E-3	NA	0	0	6E-3
Sr-90	3E-6	7E-6	2E-5	NA	0	0	3E-5
Zr-95	3E-4	7E-4	4E-5	8E-4	0	0	2E-3
Nb-95	1E-3	9E-1	6E-6	4E-6	0	0	1E-2
Mo-99	6E-3	6E-2	2E-3	3E-6	0	0	7E-2
Ru-103	2E-4	4E-3	5E-5	1E-6	0	0	4E-3
Ag-110	4E-3	2E-6	NA	NA	0	0	2E-6
Sb-124	2E-5	3E-5	1E-4	7E-5	0	0	2E-4
Cs-134	7E-4	4E-3	2E-4	2.4E-3	0	3E-6	7E-3
Cs-136	1E-4	4E-4	1E-4	NA	0	2E-6	6E-4
Cs-137	1E-3	5E-3	1E-3	4E-3	0	9E-6	1E-2
Ba-140	2E-3	2E-2	1.0E-2	4E-6	0	1E-5	3E-2
Ce-141	2E-4	2E-4	1.0E-2	7E-6	0	0	1E-2
							Total: 7E 3

Based on a 3400 MWt reactor. Noble fission gases that are not listed are less than 1 Ci/year.
* Less than 1 Ci/year for noble gas or less than 1E-4 Ci/year for radioiodine.

Table 7.1-4: Sources of Gaseous Waste and Typical Treatment Methods Used

MAIN SOURCES	TYPE OF TREATMENT
BOILING WATER REACTORS (BWR)	
Main condenser off-gas air ejector	Catalytic recombiner, filtration, delay pipe (mechanical vacuum pump) and charcoal delay
Drywell and containment purges	HEPA filter and charcoal absorber[c]
Building ventilation	
Containment	HEPA filter and charcoal absorber[c]
Auxiliary	HEPA filter and charcoal absorber[c]
Fuel handling	HEPA filter and charcoal absorber[c]
Turbine	
Radwaste	
Turbine gland seal exhaust	
PRESSURIZED WATER REACTORS (PWR)	
Stripping of primary system systems	Pressurized storage tanks & charcoal delay
Building ventilation	
Containment[a]	HEPA filter and charcoal absorber[c]
Auxiliary	HEPA filter and charcoal absorber[c]
Radwaste	HEPA filter and charcoal absorber[c]
Turbine	No treatment
Secondary	
Turbine condenser	
Air ejector	HEPA filter and charcoal absorber[c]
Turbine gland seal	Clean steam seal
Steam generator blowdown	Condenser, HEPA filter and charcoal absorber[c] (U tube only)[b]

[a] Also containment atmospheric recirculating system (filter and absorber) used to pretreat gases before release.
[b] Blowdown is not released at atmosphere in most new plant designs.
[c] Charcoal adsorption not often used in U.S. LWRs.

Adapted From: Guide to the Safe Handling of Radioactive Wastes at Nuclear Power Plants, IAEA, Vienna, 1980.

Table 7.5-1: Gaseous Waste Processing Systems at Selected PWR (Westinghouse)

Plant Name	Waste Gas Compressors (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) low level *6 - (470) high 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 cu ft waste gas surge tank. 4 charcoal beds
J.M. Farley 1&2	2 - (40)	6 - (600) normal ops 2 - (600) startup & shutdown	2 - (50)	
Shearon Harris	2 - (40)	8 - (600) normal ops 2 - (600) startup & shutdown	2 - (50)	
North Anna 1&2	#2 - (1.5)	#2 - (462)	*1 - (1.5)	
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) normal ops 2 - (600) startup & shutdown	2 - (40)	
Surry 1&2	2 - (434)		installed but not used	15.7 cu ft waste gas surge tank
Turkey Point	*2 -	*6 - (525)		
Byron 1&2	*2 - (40)	*6 - (600)		
Braidwood 1&2	*2 - (40)	#6 - (600)		
Calloway	2 - (40)	6 - (600) normal ops 2 - (600) startup & shutdown	2 - (50)	
Catawba	2 - (40)	6 - (600) normal ops 2 - (600) startup & shutdown	2 - (50)	
Comanche Peak	2 - (40)	8 - (600) normal ops 2 - (600) startup & shutdown	2 - (50)	
D.C. Cook	*2 - (40)	*8 - (600)		
Diablo Canyon	3 - (40)	3 - (705)		
McGuire 1&2	2 - (40)	8 - (600) normal ops 2 - (600) startup & shutdown	2 - (50)	
Millstone 3		Process gas receiver	Letdown degassifer 120 gpm capacity. 2 - 13,650# charcoal beds	
Salem	2 - (40)	4 - (525)		
Seabrook 1&2	5 - (1.2-11.3)		5 - 1,600# charcoal beds	
Sequoyah 1&2	*2 - (40)	*9 - (600)		
Trojan	2 - (39)	4 - (625)		29 cu ft waste gas surge tank
Votgle 1&2	2 - (40)	7 - (600) normal ops 2 - (600) startup & shutdown	3 - (50)	
Wolf Creek	2 - (40)	6 - (600) normal ops 2 - (50) 2 - (600) startup & shutdown		
Zion 1&2	*2-(40)	*6-(600)		

* COMMON TO BOTH UNITS

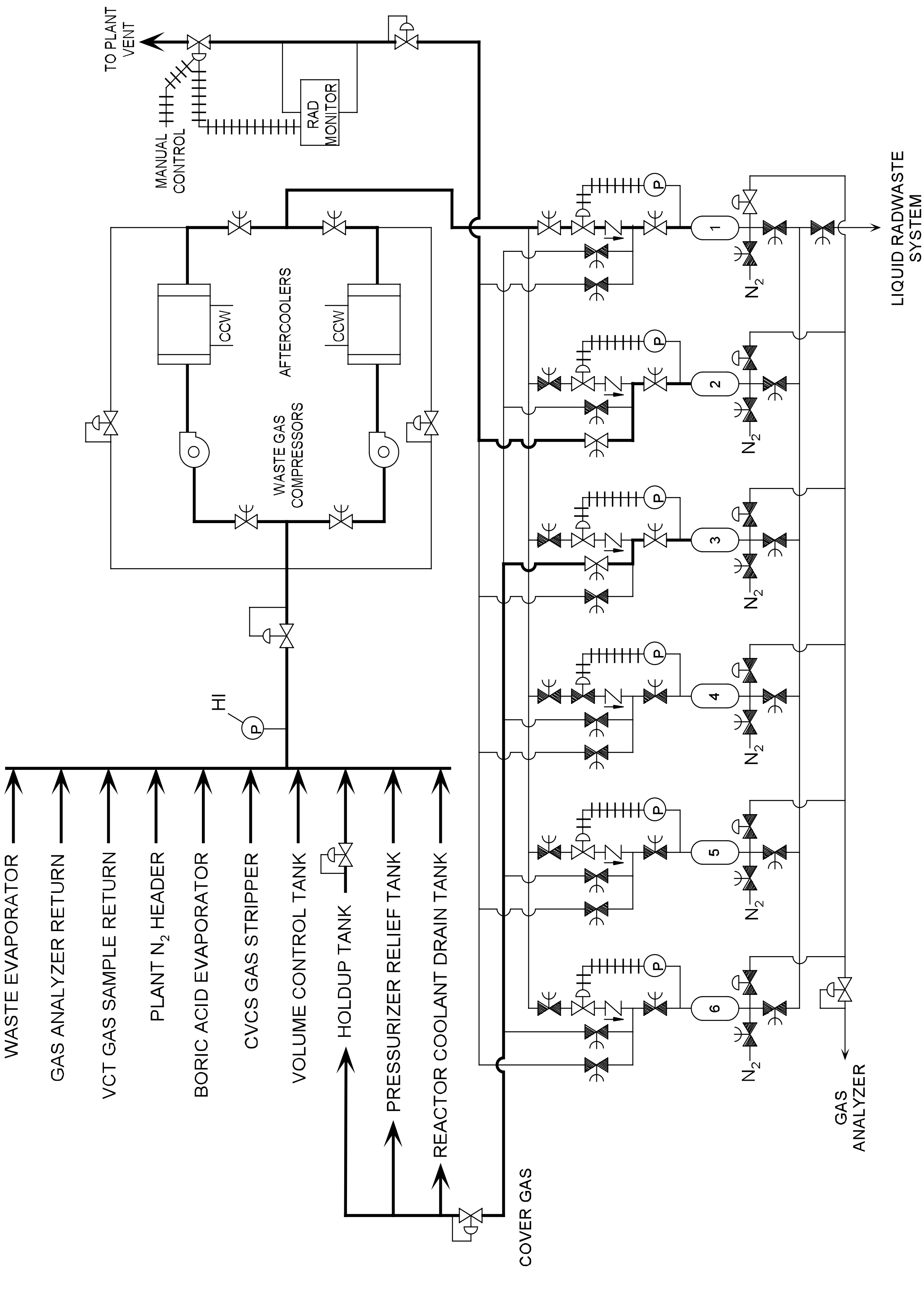

Figure 7.5-1 Typical PWR Gaseous Radioactive Waste Processing Systems

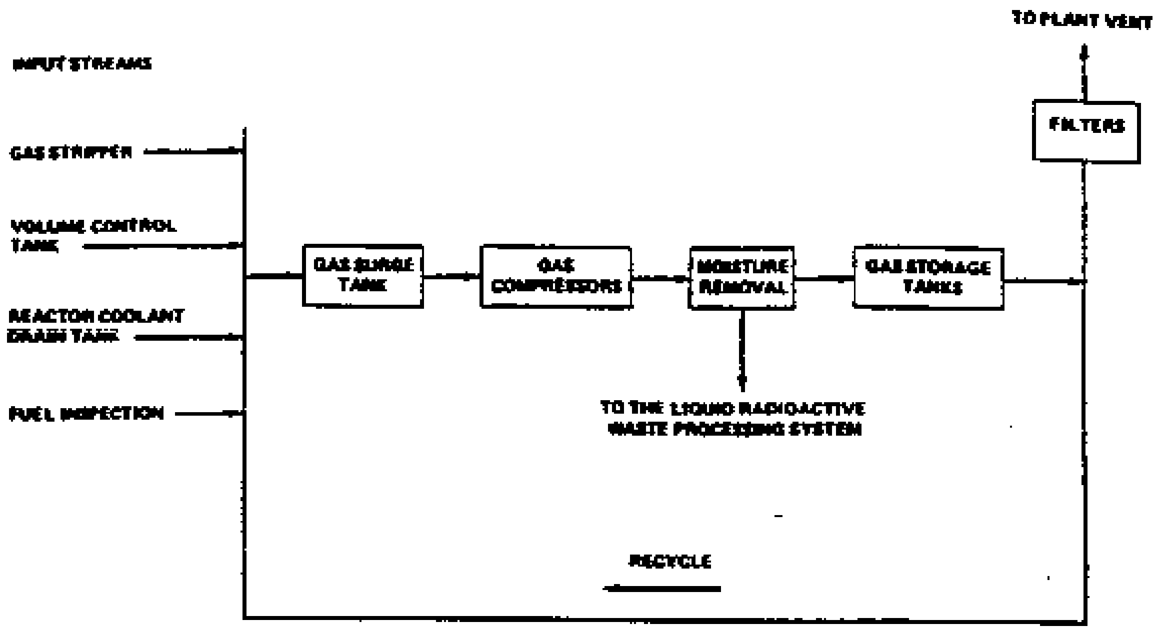

Figure 7.5-2 Typical PWR Tank Storage System

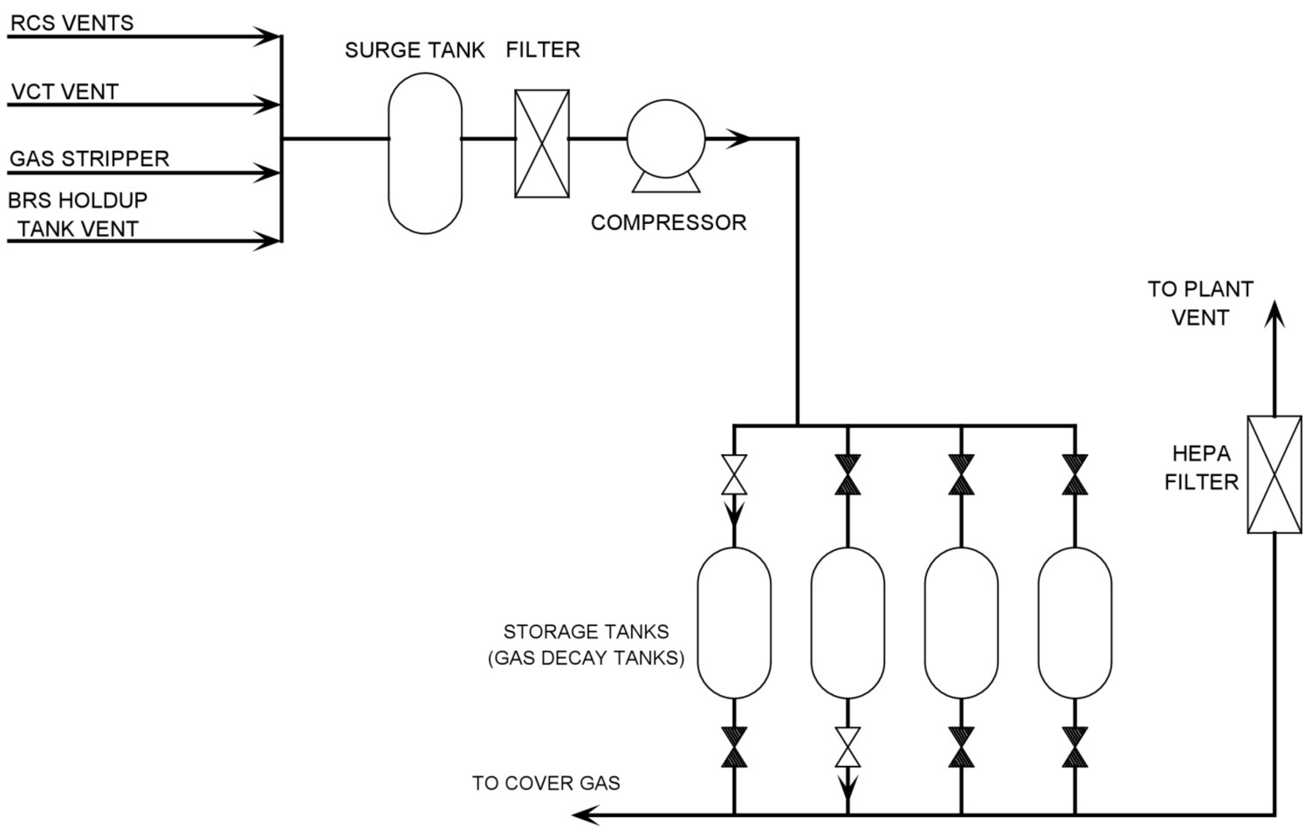

Figure 7.5-3 Typical PWR Storage and Release Type Gaseous Radwaste System

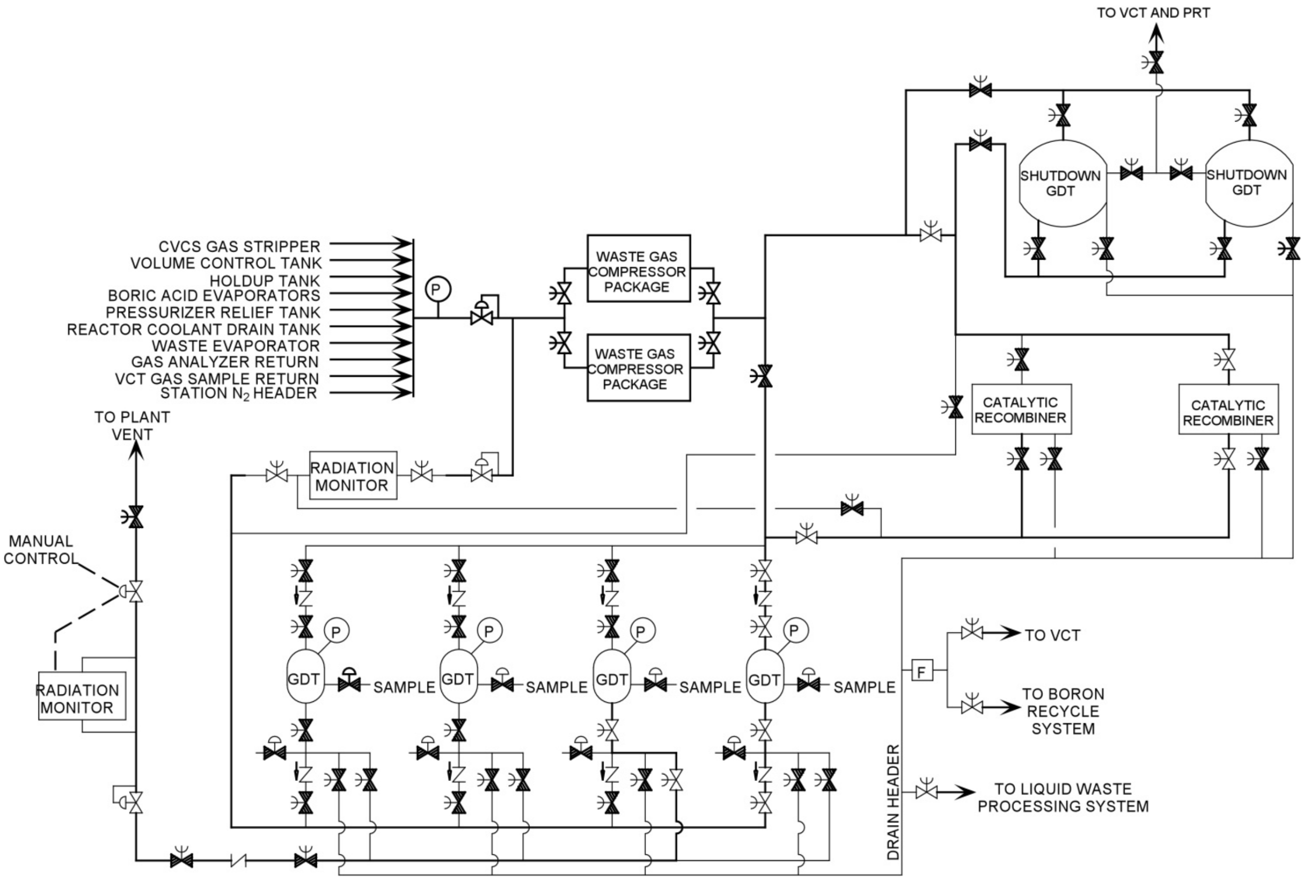

Figure 7.5-4 Typical PWR Volume Reduction Extended Storage System for Use with CVCS Stripping

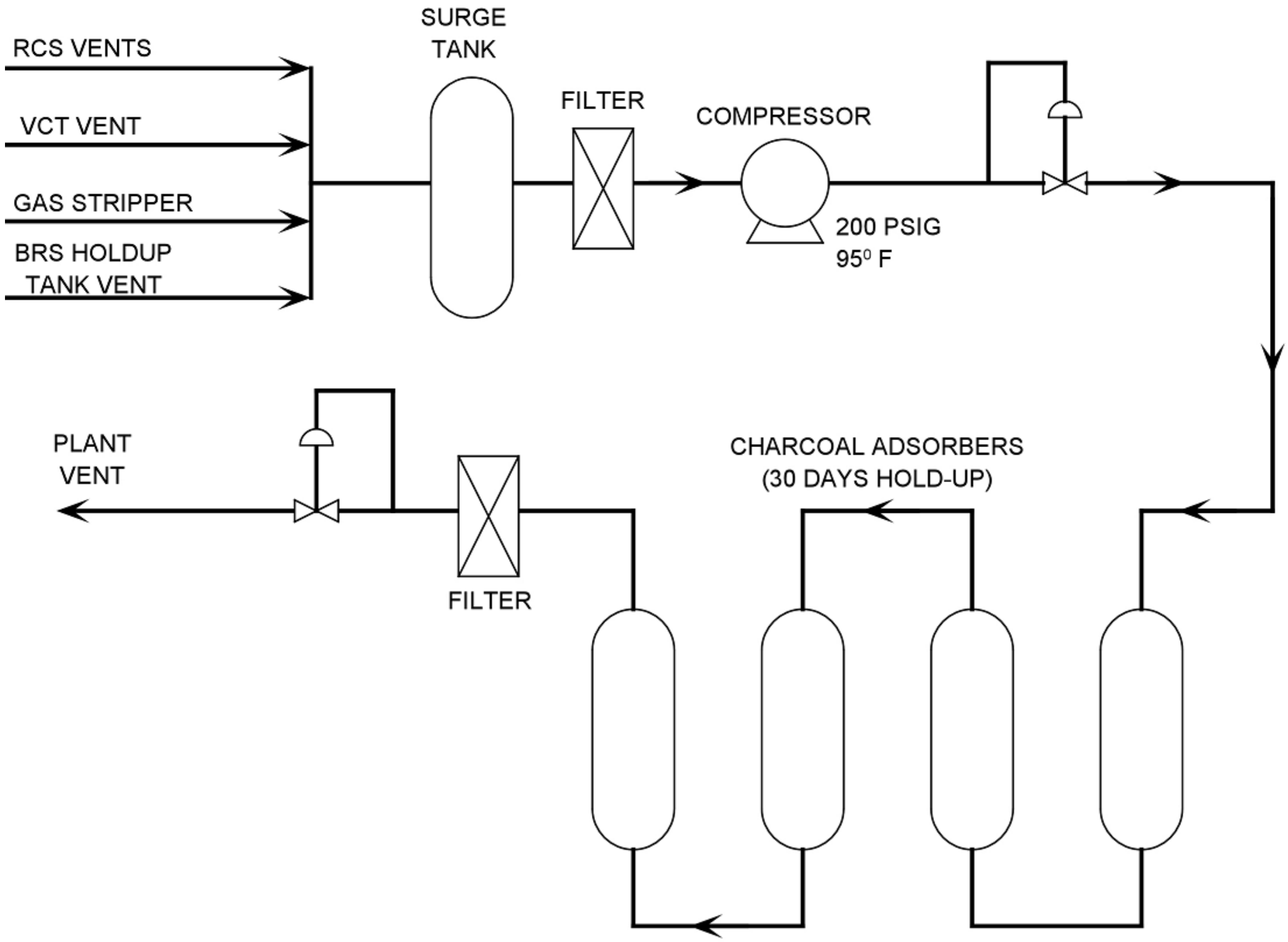

Figure 7.5-5 Typical PWR Adsorption Type Waste Gas Processing System

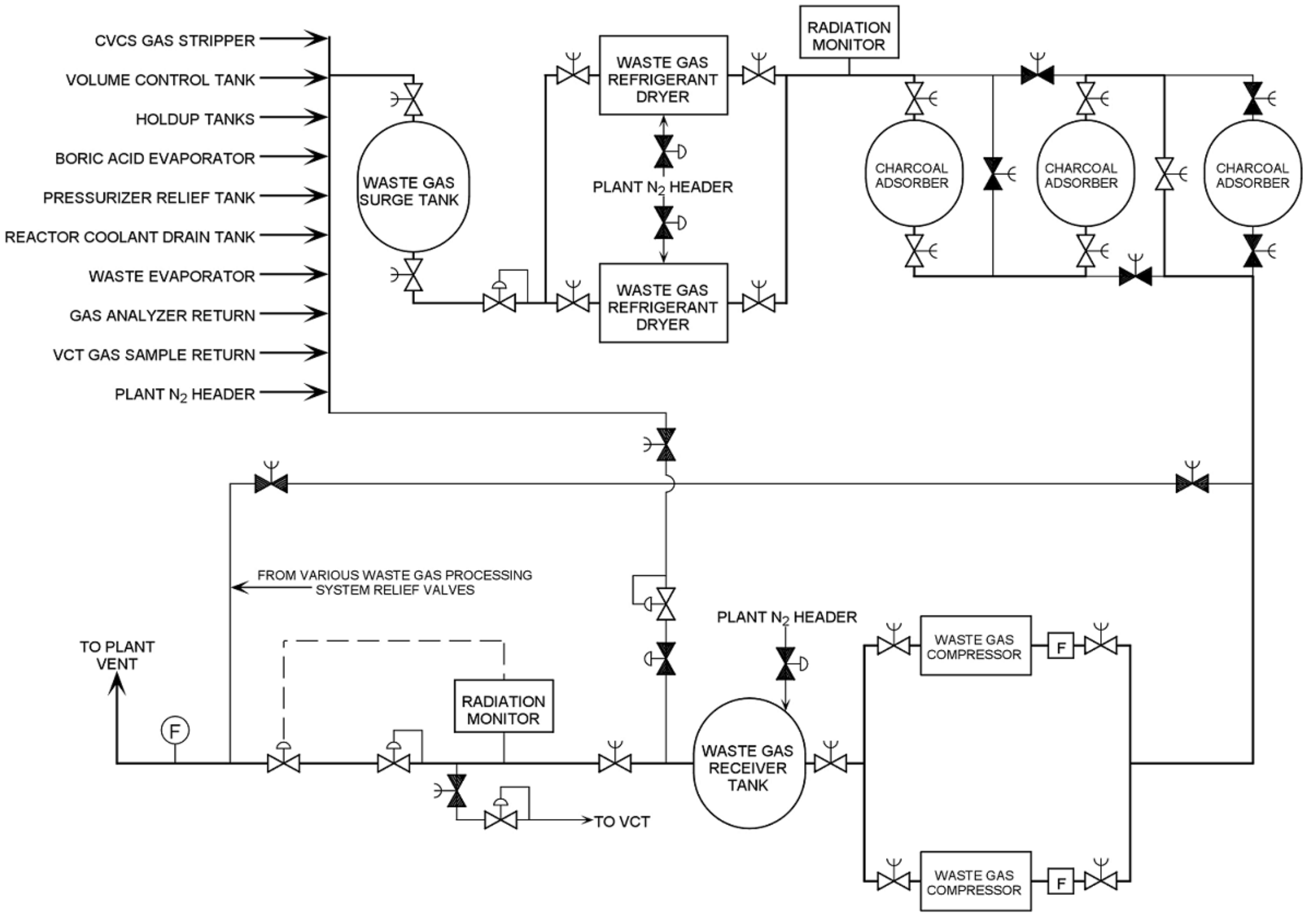

Figure 7.5-6 Ambient Charcoal System Used to Clean the PWR Off Gas (Flow Sheet)

Table 7.9-1: Noble Gases Processed by the BWR Off Gas System

NUCLIDE	HALF-LIFE	FISSION YIELD (%)
Xe-138	14.2 Minutes	6.235
Kr-87	76.0 Minutes	2.367
Kr-88	2.79 Hours	3.642
Kr-85m	4.4 Hours	1.332
Xe-133m	9.16 Hours	6.723
Xe-133	5.27 Days	6.776
Xe-135m	15.7 Minutes	0.05
Kr-85	10.76 Years	.27

Note: There are 22 noble gases resulting from fission of U-235 that are summed, all but the first six above are insignificant at the air ejector. If a recombiner is used, only Xe-133 (and Kr-85) are of consequence at the plant release point.

Table 7.9-2: Off Gas System Component Operating Characteristics

STEAM AIR EJECTOR	
Normal Flow rate	100-200 scfm
CATALYTIC RECOMBINER	
Inlet Temperature	350°F
Outlet Temperature	798°F
Operating Pressure	2 psia
Maximum Pressure Drop	13" W.C.
Maximum Hydrogen (outlet)	16 ppm
Full Power Flow (air)	155 scfm (max)
	3 scfm (min)
(hydrogen)	95 scfm
(oxygen)	47.5 scfm
OFF-GAS CONDENSER	
(TUBE SIDE- condensate)	
Inlet Temperature	110°F
Outlet Temperature	112°F
Maximum Pressure	235 psia
Normal Flow	9.8 E6 lb/hr
(SHELL SIDE- gas/stream)	
Inlet Temperature	830°F
Outlet Temperature	130°F
Maximum pressure	19.2 psia
Normal Flow	7071 lb/hr
WATER SEPARATOR	
THIRTY-MINUTE HOLDUP PIPE	
Holdup pipe	36"dia x 997', 6280 cf
MOISTURE SEPARATOR	
Max. Pressure Drop	1.2 " water
Inlet Temperature	45°F
Inlet Pressure	18.1 to 14.8 psia
PREFILTER	
Normal Air Flow	11.5 scfm
Max. Air Flow	15.5 scfm
Pressure Drop	1" water
CHARCOAL ABSORBERS	
Number of vessels	12
Flow rate	11.5 scfm
Mass	36 tons (3 ton/vessel)
Gas Holdup (Xenon/(Krypton)	14.6 days / 19.4 days

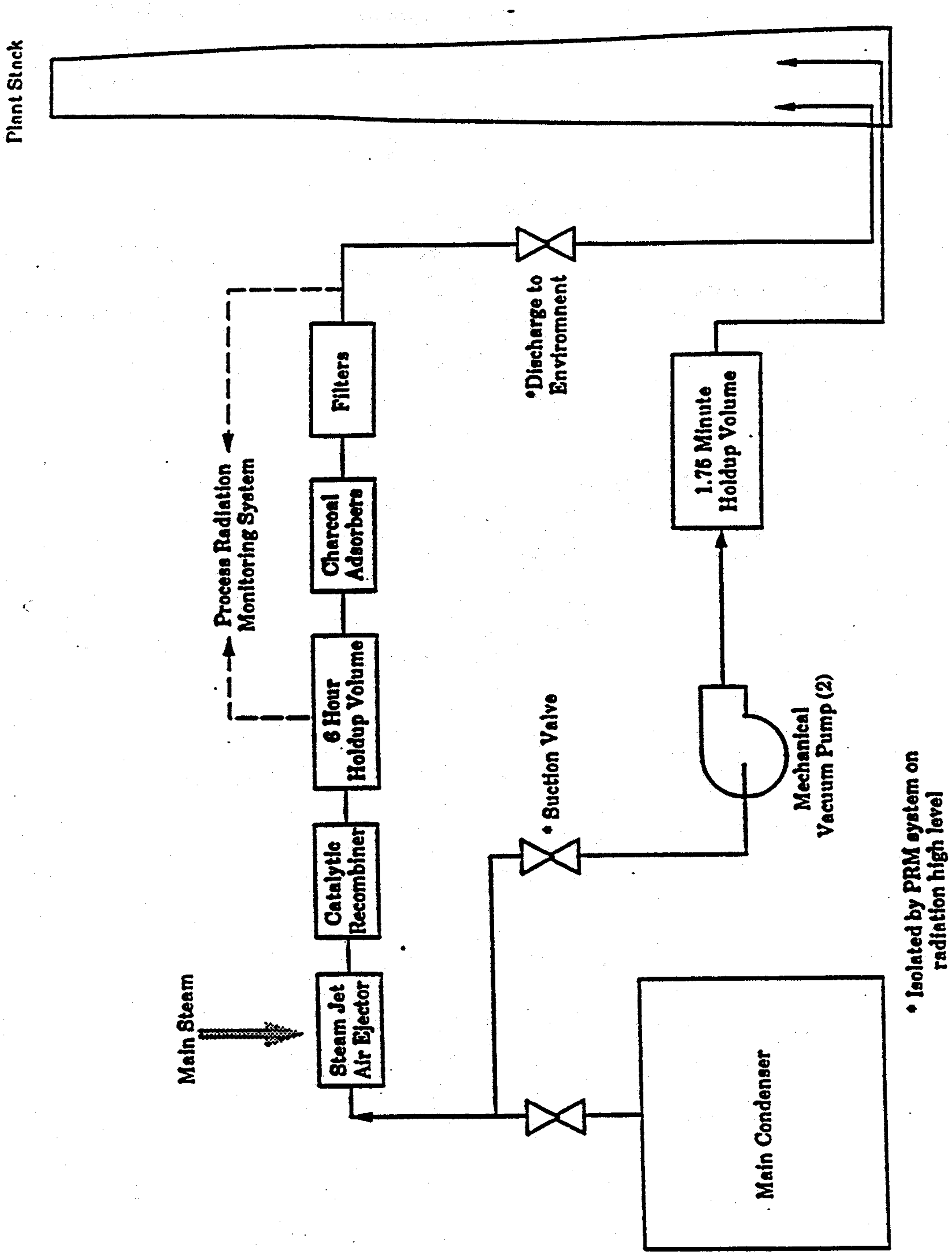

Figure 7.9-1 BWR Off-Gas System

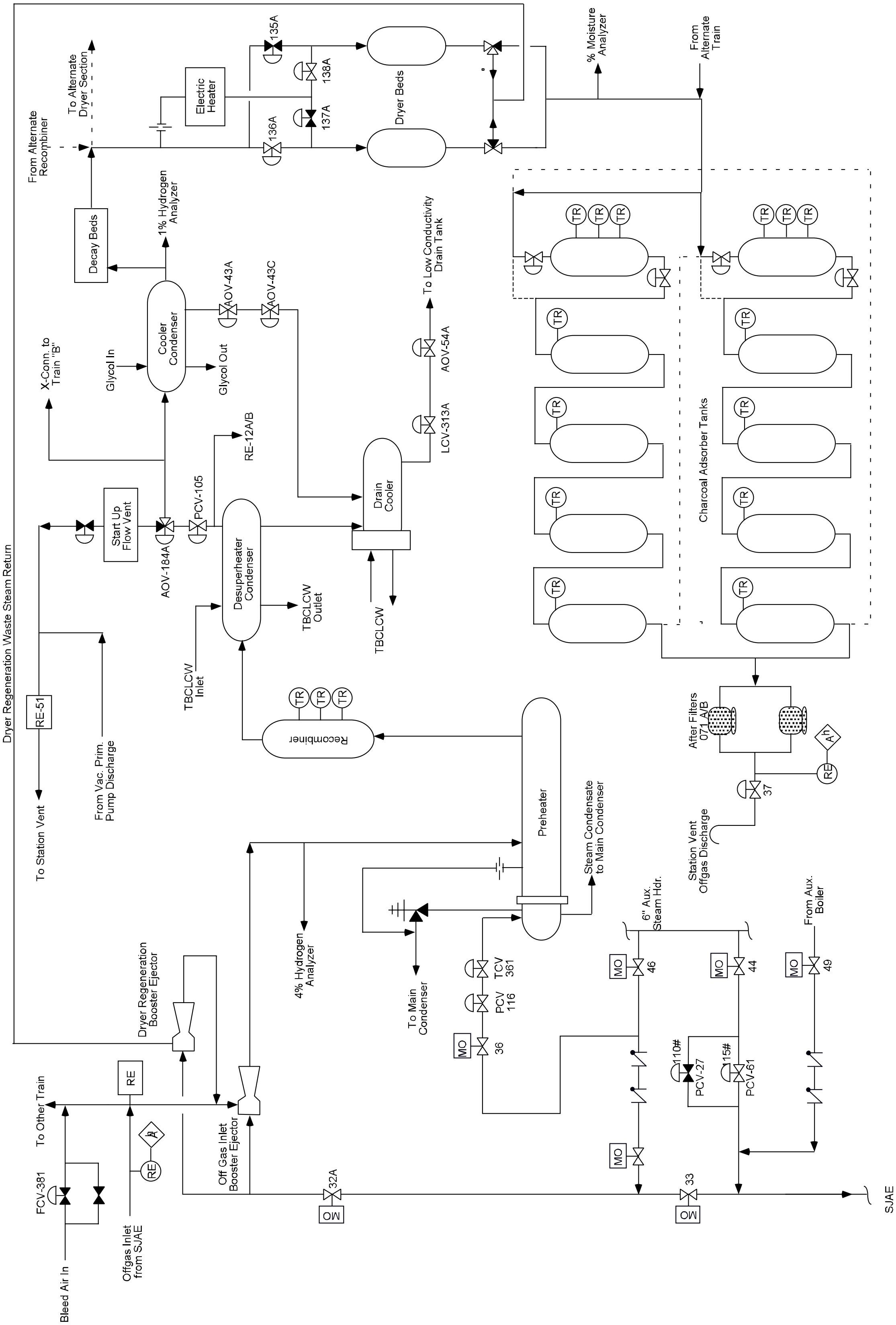

Figure 7.9-2 BWR Off-Gas System Schematic Arrangement

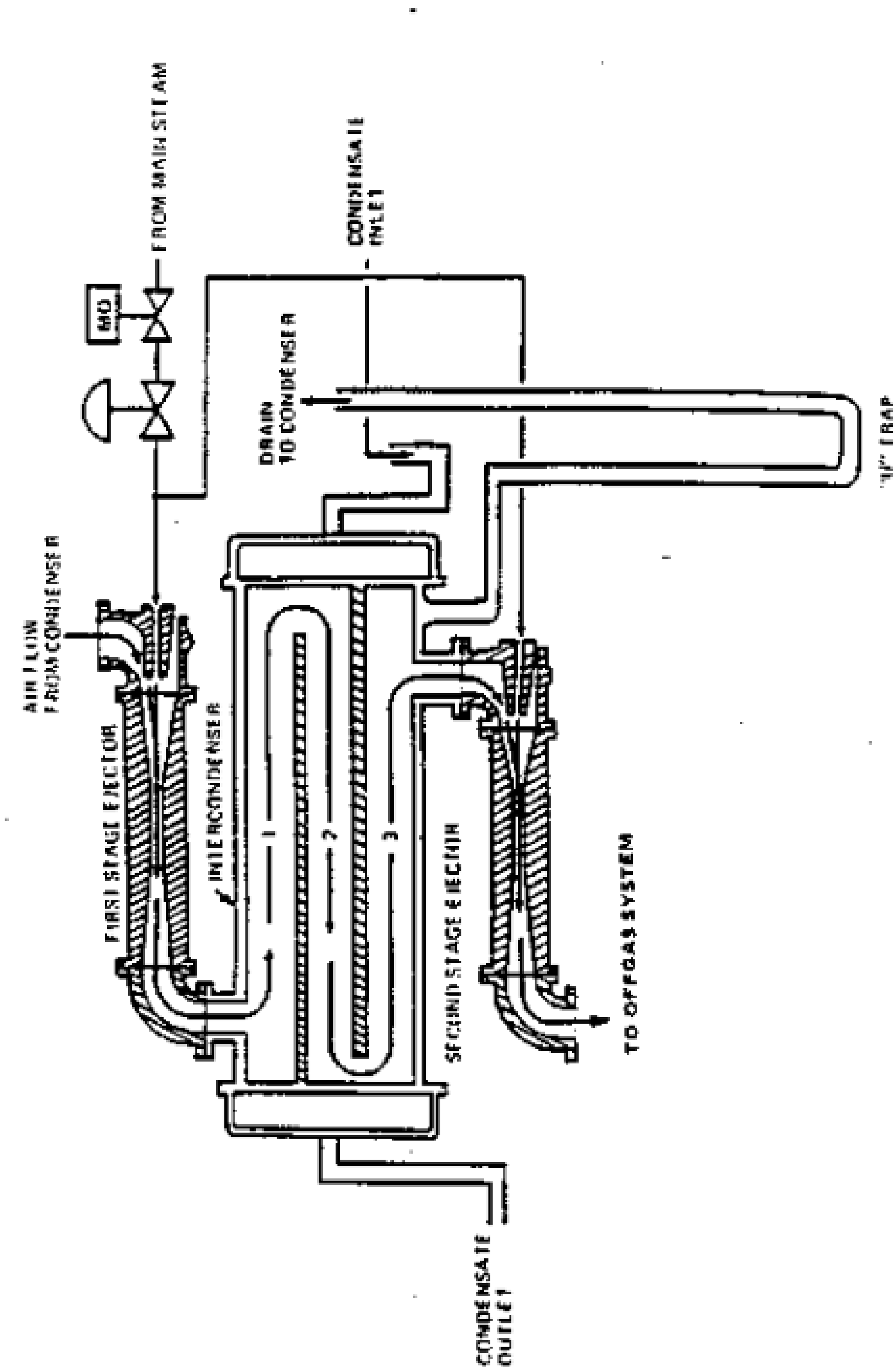

Figure 7.9-3 Off-Gas SJAE Arrangement

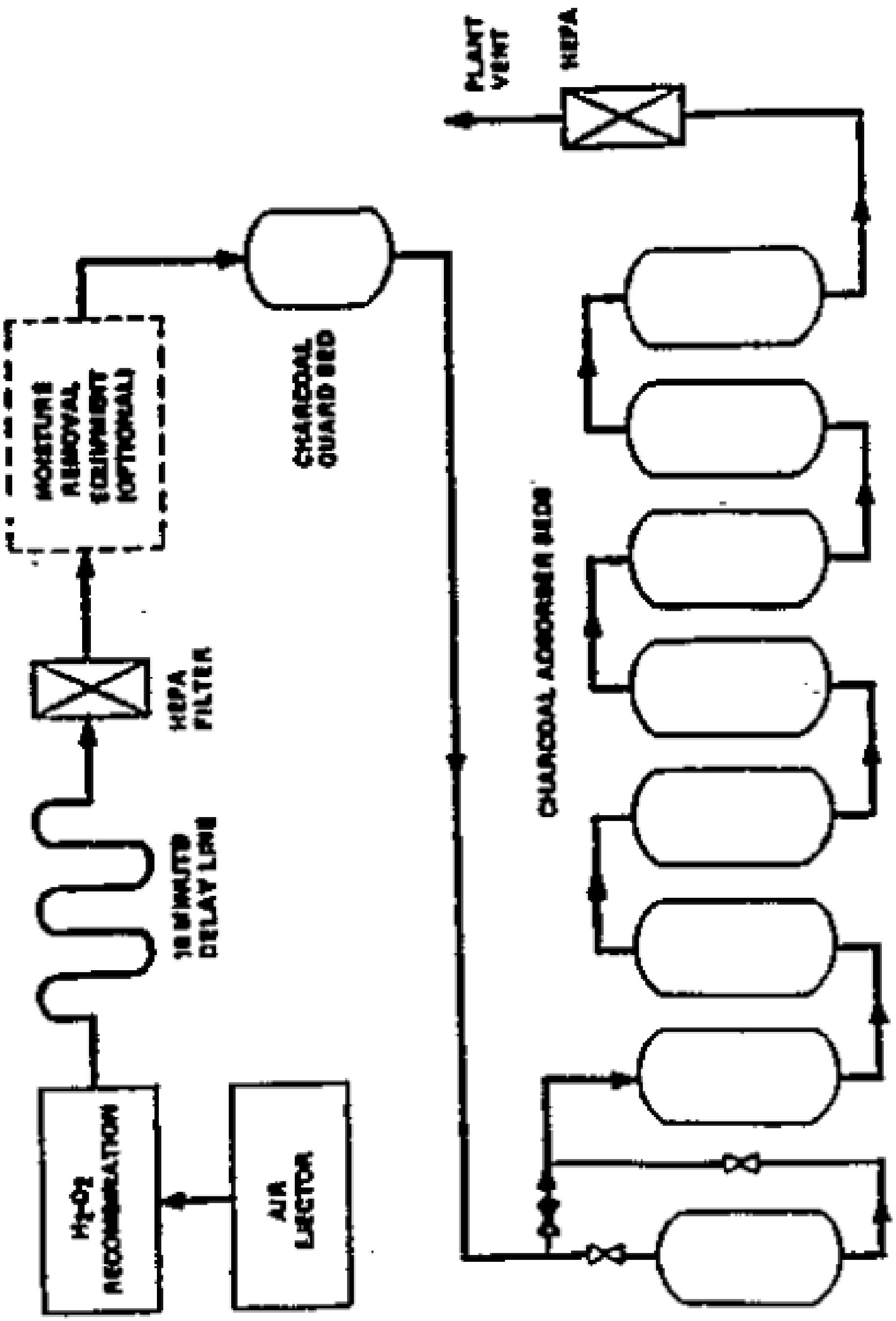

Figure 7.9-4 BWR Charcoal Absorber System