11.3 Gaseous Waste Management Systems

Fission product gases and radiolytic decomposition gases (including xenon and krypton) are generated in the reactor, dissolve in the reactor coolant, and are transported to various systems in the plant by process fluid interchanges. Reactor coolant leakage also releases a portion of these gases to the ambient building atmosphere. Additionally, some hydrogen and oxygen are generated by radiolytic decomposition of the reactor coolant and hydrogen is added to the reactor coolant by the volume control system for oxygen control. Although airborne releases can be limited by restricting reactor coolant leakage and by limiting the concentrations of radioactive gases in the reactor coolant system (RCS), these gases escape from reactor coolant during normal operations and require treatment in the gaseous waste processing system. The gaseous waste processing system and other ventilation systems combine to form the gaseous waste management system. During a design basis accident (DBA) or failure, radioactive gases or airborne particulates are released to the ambient atmosphere in the buildings and are managed by the combined operation of the containment ventilation, safeguard building controlled area ventilation, fuel building ventilation, nuclear auxiliary building ventilation, and sampling activity-monitoring systems. A description of the design and operation of these ventilation systems is presented in Section 9.4, Design Basis. In addition, Section 12.3.3 provides information on these ventilation systems and air filtration related to radioactivity control.

The primary design functions of the gaseous waste processing system are to collect radioactive waste gases from the various systems in which they are released, to process these waste gases and provide sufficient holdup time for radioactive decay to reduce the activity present, and to control the subsequent release of processed waste gases to the atmosphere in compliance with regulatory limits. A safety-related secondary design function of the gaseous waste processing system is containment isolation for system piping that penetrates the Reactor Building. Because the purge lines connecting the pressurizer relief tank and the reactor coolant drain tank to the system penetrate containment, isolation valves are installed on both sides of the penetration and automatically close when the reactor protection system containment isolation signal is received.

11.3.1 Design Basis

The U.S. EPR gaseous waste management system is designed to meet the individual dose limits and compliance specified in 10 CFR 20.1301 and 20.1302 and the ALARA design objectives of 10 CFR Part 50, Appendix I. In addition, effluent concentrations are well below the annual average concentration limits of 10 CFR Part 20, Appendix B, Table 2. The ALARA design objectives are consistent with the Environmental Radiation Protection Standards for Nuclear Power Operations of 40 CFR Part 190 as implemented under 10 CFR 20.1301(e). The gaseous waste processing system is designed to fulfill these primary design functions under modes of normal plant operation. The gaseous waste processing system is not designed to mitigate DBAs.

Using the methodology contained in RG 1.143, the gaseous waste processing system is classified as RW-IIa (High Hazard). This classification is based on calculation of the limiting total design basis unmitigated radiological release and considers the maximum inventory of a given radwaste system at the boundary of the unprotected area.

Consistent with the requirements of 10 CFR 20.1406, the U.S. EPR, including the gaseous waste management system, is designed, to the extent practicable, to minimize contamination of the facility and the environment, facilitate eventual decommissioning, and minimize, the generation of radioactive waste. Minimization of contamination and radioactive waste generation is described in Section 12.3.6.

11.3.1.1 Design Objectives

In addition to fulfilling its primary design functions, the gaseous waste processing system meets the following design objectives:

- Compensate for level deviations in the free gas atmosphere of tanks that are connected to the system by adding or removing the free gas.
- Maintain a negative system pressure to prevent the escape of radioactive gases from components connected to the building air.
- Limit the hydrogen and oxygen concentrations in the system and connected systems to less than the flammability limits of the respective gas mixtures.
- Minimize the release of radioactive gases to the environment by injecting the processed purge gas back into the quasi-closed loop.
- Handle excess gas flow rates due to the movement of reactor coolant during plant startup and shutdown.
- Maintain a positive pressure in the delay system to improve the adsorption properties of the activated charcoal.
- Limit the oxygen concentration to less than 0.1 percent by volume downstream of the recombiner in order to minimize the amount of oxygen reabsorbed into the reactor coolant.

11.3.1.2 Design Criteria

The gaseous waste processing system is subject to the following GDC found in 10 CFR Part 50, Appendix A:

- GDC 3 requires that structures, systems, and components important to safety be designed and located to minimize, consistent with other safety requirements, the probability and effect of fires and explosions.
- GDC 60 requires that nuclear power unit design include means to suitably control the release of radioactive materials in gaseous effluents produced during normal reactor operation, including AOOs. This requirement includes providing sufficient holdup capacity for retention of gaseous effluents containing radioactive materials.
- GDC 61 requires in part that radioactive waste systems be designed to provide adequate safety under normal and postulated accident conditions. Radioactive waste systems must be designed with a capability to permit appropriate periodic inspection and testing of components important to safety; with suitable shielding for radiation protection; and with appropriate containment, confinement, and filtering systems.

11.3.1.2.1 Quality Group Classification

Design criteria pertinent to systems classified as RG 1.143 safety classification RW-IIa (High Hazard) and tabulated in RG 1.143, Table 2 (Natural Phenomena and Internal/External Man-Induced Hazard), Table 3 (Design Load Combinations), and Table 4 (SSC Design Capacity Criteria) are used in design analyses of the gaseous waste management system. The containment isolation valves and intervening piping are classified as Quality Group B, as defined and addressed in Section 3.2. Other components of the gaseous waste management system are classified as Quality Group D due to the significant licensing requirements or commitments in RG 1.143.

11.3.1.2.2 Seismic Design Classification

The components of the gaseous waste management system except the containment isolation valves and associated piping are classified as Radwaste Seismic (RS). The containment isolation valves and intervening piping are classified as Seismic Category I, as defined and addressed in Section 3.2. Structures, systems, and components of this system that are classified as RG 1.143 classification RW-IIa (High Hazard) are designed to withstand seismic loading equivalent to one-half the amplitude of the safe shutdown earthquake (SSE).

11.3.1.2.3 Controlled Release of Radioactivity

Expected Releases

The U.S. EPR is designed to meet ALARA design objectives for gaseous releases due to plant operation. Section 11.3.3 describes the calculated releases from the gaseous waste processing system and from the Containment Building, Safeguard Building controlled area, Nuclear Auxiliary Building, Radioactive Waste Processing Building, and fuel building ventilation systems. Section 11.3.3 also contains a demonstration that the doses to individuals at or beyond the site boundary arising from the combined expected releases from the gaseous waste management systems meet ALARA design objectives.

Release Monitoring

Releases from the gaseous waste processing system are continuously monitored by radiation sensors in the delay system discharge line. The system also provides for grab sample collection for analysis from several different points on the process stream, and from each of the delay beds along the discharge line. Gaseous waste processing system releases are routed through the filtration system of the nuclear auxiliary building ventilation system.

Building ventilation exhausts are processed in the filtration system of the nuclear auxiliary building ventilation system or in the “low flow purge” in the containment purge subsystem of the containment ventilation system. These exhausts are routed through the nuclear auxiliary building ventilation stack for release to the environment. Radiation detectors in the stack continuously monitor the exhaust gases released from the nuclear auxiliary building ventilation system.

Operator Error or Equipment Malfunction

The radiation sensors in the gaseous waste processing discharge line generate alarms in the main control room. Few operator actions are required during gaseous waste system operation because the system is mostly automated.

11.3.2 System Description

The U.S. EPR gaseous waste processing system, as shown in Figure 11.3-1—Gaseous Waste Processing System, Normal Operation, combines a quasi-closed loop purge system with a discharge path provided through the delay system. The purge system recycles the majority of processed purge gas. This recycle reduces the system demand for makeup purge gas and limits the amount of gas that must be discharged through the delay system. The purge system includes the following equipment:

- Waste gas compressors.
- Purge gas predrier.
- Purge gas reducing stations.
- Purge gas supply piping to tanks in interfacing systems.
- Purge gas return piping from tanks.
- Purge gas drier.

- Recombiner.
- Gas cooler.

The purge system also includes a gas supply subsystem, gas measuring subsystems, and compressor sealing subsystems. The purge gas is nitrogen; small quantities of hydrogen and oxygen, and trace quantities of noble gas fission products also are present in the purge gas stream.

The delay system includes a gel drier, delay beds, gas filter, and discharge gas reducing station. The delay system discharges processed gaseous waste to the nuclear auxiliary building ventilation system for release to the ambient atmosphere via the ventilation exhaust stack.

The components of the gaseous waste processing system and the majority of the components of connected systems are located in the Nuclear Auxiliary Building. Several components that are continually swept by gaseous waste processing purge gas flow are located in other buildings. The volume control tank and two of seven Nuclear Island (NI) drain and vent system primary effluent tanks are located in the Fuel Building. Four more NI drain and vent systems are located in each of the four Safeguard Buildings. The pressurizer relief tank and the reactor coolant drain tank are located in the Reactor Building. Gaseous waste processing system piping is routed among the buildings.

Table 11.3-1—Gaseous Waste Processing System Parameters lists key design parameters for the gaseous waste processing system. Table 11.3-2—Gaseous Waste Processing System Component Data describes the components of the gaseous waste processing system. Figure 11.3-2—Gaseous Waste Processing System, Gaseous Waste Sources shows the sources of input, and point of discharge for the gaseous waste processing system.

11.3.2.1 Normal Operation

The gaseous waste processing system is designed to operate continuously during normal plant operation. For the majority of this time, with the plant operating at full power, the gaseous waste processing system operates in a steady state mode, with a constant flow rate through the purge system and a small, constant discharge rate from the delay system.

11.3.2.1.1 Normal Operation—Purge System

The circulation of purge gas is maintained by the operation of one or both waste gas compressors. The gaseous waste processing system operates at positive pressure from the waste gas compressors to the reducing stations and the volume control tank. The system operates at subatmospheric pressure downstream of the reducing stations through the various connected tanks and the gaseous waste processing equipment that returns the purge flow to the suction of the waste gas compressor.

Radioactive fission product gases are collected from the pressurizer relief tank, the reactor coolant drain tank, and the volume control tank. The primary influent source is the coolant degasification system, which extracts both hydrogen and fission product gases from the reactor coolant. The other major source of influent to the gaseous waste processing system is the reactor coolant drain tank.

Gaseous waste processing system purge gas, drawn from the connected components, is routed through the gaseous waste processing equipment. The gas drier first treats the returning purge gas using a cooling process to reduce the moisture content in the purge gas. Next, the recombiner uses a catalytic process at elevated temperature to recombine the free hydrogen and oxygen entrained in the purge gas stream.

The gas cooler cools the purge gas stream at the recombiner outlet. A filter at this point prevents particulates from carrying forward to the waste gas compressor. Next, the waste gas compressor compresses the incoming purge gas flow and discharges it to the sealing liquid tank. The sealing liquid tank then separates the gaseous and liquid phases. The purge gas leaving the sealing liquid tank is routed to the pre-drier. The pre-drier cools the purge gas and reduces its moisture content by condensation.

The gaseous waste processing system piping splits into three branches downstream of the pre-drier, dividing the purge gas flow. One branch of the piping supplies purge gas to the pressurizer relief tank and the reactor coolant drain tank. The second branch supplies purge gas flow to the volume control tank. The third branch routes purge gas to the delay system. Under normal system operating conditions, the purge gas enters the delay system and is directed through the reverse flow path of the gel drier and into the purge gas supply line. This configuration provides for regeneration of the gel drier desiccant.

The purge gas flow in the third branch is joined by the purge gas discharged from the volume control tank, and is then distributed to four parallel paths. These four paths purge radioactive fission product gases from the coolant supply and storage system tanks, reactor boron and water makeup system, coolant purification system, coolant treatment system, coolant degasification system, nuclear sampling active liquid samples subsystem, and various NI drain and vent system primary effluent tanks (in the Safeguard Buildings, the Fuel Building, and the Nuclear Auxiliary Building).

11.3.2.1.2 Normal Operation—Delay System

Only a small quantity of purge flow is sent to the delay beds under normal operating conditions; most of the purge flow is recycled. A constant positive pressure is maintained on the delay beds for favorable adsorption of waste gases in the activated charcoal media. This provides sufficient holdup time for natural decay processes to reduce the activity among the fission product gases before they are released from the delay beds so that 10 CFR 20.1301 dose limits are not exceeded.

11.3.2.2 Surge Gas Operation

Operations that transfer large quantities of primary coolant in the systems purged by the gaseous waste processing system automatically place the system into surge gas operation mode. The gaseous waste processing system operates in surge gas mode primarily during plant startup or shutdown.

11.3.2.2.1 Surge Gas Operation—Purge System

Plant operating mode has little effect on the operation of the gaseous waste processing system purge system. Purge flow through the components connected to the gaseous waste processing system continues as in normal operating conditions.

11.3.2.2.2 Surge Gas Operation—Delay System

During conditions of excess gas generation, the flow volume to the delay system automatically increases. This increased flow volume is automatically sensed and shifts the system to surge gas operation mode. Surge gas operation mode automatically stops waste gas releases from the gaseous waste processing system via the nuclear auxiliary building ventilation system until the system is manually reset.

The capacity of the delay system adapts to the increased flow rate during surge gas operation mode because surge gas mode elevates delay system pressure. Higher pressure increases the storage capacity of the delay system and improves the adsorption capabilities of the activated charcoal. Surge gas operation continues for a predetermined period of time that is sufficient to achieve the required residence times for the fission product gases. When this time period expires, delay system pressure reduction is manually initiated, which gradually reduces the pressure in the delay system.

11.3.2.3 Component Description

This section provides detailed descriptions of the individual components that make up the systems described in Section 11.3.2. Table 11.3-2 lists key design and operating parameters for gaseous waste processing system components.

11.3.2.3.1 Waste Gas Compressors

The waste gas compressors take suction on the purge gas in the subatmospheric portion of the purge system, compress the purge gas, and discharge it to the positive pressure portion of the purge system. The waste gas compressors move the purge gas flow around the quasi-closed purge system and force the gas into the delay system. The waste gas compressors are liquid ring compressors with canned motors. Liquid ring compressors are used because they do not present an ignition source. Demineralized water seals the impeller, lubricates the bearings, and cools the motor.

11.3.2.3.2 Sealing Liquid Tanks

The sealing liquid tanks separate the compressed purge gas from the sealing liquid discharged from the waste gas compressors and store the sealing liquid for reuse. The sealing liquid tanks are stainless steel cylindrical pressure vessels.

11.3.2.3.3 Pre-drier

The pre-drier is a stainless steel shell and tube heat exchanger. The operational chilled water system provides cooling liquid to the tubes. The pre-drier reduces the moisture content and dewpoint of the purge gas downstream of the waste gas compressor to protect expansion valves from icing, to promote regeneration of the gel drier during normal gaseous waste processing system operations, and to protect the hydroscopically sensitive activated charcoal in the delay beds.

11.3.2.3.4 Reducing Stations

Nine reducing stations in the gaseous waste processing system control pressures and flows in various portions of the system. Reducing stations 1, 2, 3, 7, 8, and 9 control pressure. Reducing stations 4, 5, and 6 maintain a specified constant flow rate to the pressurizer relief tank, reactor coolant drain tank, and the volume control tank, respectively. Each reducing station consists of one or more motor-operated control valves and associated pressure control instrumentation loops. Reducing stations that contain more than one control valve are configured with the control valves installed in parallel; each control valve is sized to control 100 percent of the system flow at that point, allowing one valve to be isolated for maintenance. Certain control loops have multiple setpoints that are automatically changed if the system enters a different operating mode (such as surge gas operation).

11.3.2.3.5 Gas Drier

The gas drier is a stainless steel shell and tube heat exchanger that reduces the moisture content of the purge gas stream returning to the recombiner. The gas drier condenses water vapor from the purge gas stream to provide more favorable conditions for recombiner operation. The operational chilled water system provides cooling liquid to the tubes in the gas drier. A gas filter is located near the gas drier outlet to further remove condensed water from purge gas stream.

11.3.2.3.6 Recombiner

The recombiner is a stainless steel, cylindrical pressure vessel filled with palladium-doped, porous, spherical aluminum-oxide pellets. The recombiner also contains three electric heating rods. The recombiner catalytically combines free hydrogen and oxygen gas present in the purge gas return stream into water to prevent potentially explosive accumulations of these gases in the gaseous waste processing system and connected components. The recombiner operates at elevated temperatures so that the water formed remains in the vapor state and does not precipitate on the catalyst (where it interferes with the catalytic chemical reaction). The chemical reaction that combines gaseous hydrogen and oxygen into water is exothermal; the energy released by that reaction also contributes to heat the recombiner. The recombiner is designed to remove gaseous hydrogen concentrations of up to four percent by volume of the purge gas stream; it simultaneously removes gaseous oxygen concentrations of up to two percent by volume from that stream.

11.3.2.3.7 Gas Cooler

The gas cooler reduces the temperature of the purge gas stream discharged from the recombiner. The gas cooler protects the waste gas compressors from operation at high temperatures, which can shorten compressor service life. The gas cooler is a stainless steel shell and tube heat exchanger. The operational chilled water system provides coolant to the tubes in the gas cooler. A filter located near the gas cooler outlet screens dust and particulates from the purge gas stream.

11.3.2.3.8 Gel Drier

The gel drier removes moisture from the waste gas stream entering the delay system during surge gas operation, which protects the hydroscopically sensitive activated charcoal in the delay beds. The stainless steel gel drier is a cylindrical pressure vessel. The desiccant in the gel drier is a silica gel consisting of porous spherical particles made of amorphous silicon dioxide. In the lower part of the gel drier, the silica gel used is not sensitive to liquid water. In the upper part of the gel drier, the silica gel used is sensitive to liquid water, but has enhanced adsorption properties.

Two motor-operated valves located in the piping interface between the purge system and the delay system control the direction of gas flow through the gel drier. Under normal conditions, the purge gas stream enters the top of the gel drier, flows down through the two types of silica gel desiccant, then returns to the purge system through reducing station 2. When the gaseous waste processing system automatically switches to surge gas operation, gas flow is redirected through the gel drier in the opposite direction for adsorptive drying en route to the delay beds.

11.3.2.3.9 Delay Beds

The delay beds retain the radioactive fission product gases that enter the delay system. These gases (e.g., xenon and krypton) are dynamically adsorbed by the activated charcoal media in the delay beds, which provides the holdup times required for natural decay. The holdup time for xenon is 27.7 days and the holdup time for krypton is 40 hours.

The delay beds consist of three vertical pressure vessels connected in series. Two moisture sensors are configured in parallel upstream of the delay beds to provide warning and interlock signals if the moisture content of waste gas entering the delay beds exceeds acceptable levels. A radiation sensor is also located upstream of the delay beds to monitor influent activity levels. Two pressure sensors monitor pressure upstream of the delay beds to provide warning signals for high or low operating pressure conditions and to provide interlock signals.

11.3.2.3.10 Delay Line Gas Filter

The gas filter downstream of the delay beds protects reducing station 3 by removing particles that are generated in or passed through the delay beds, such as solid decay products or charcoal dust. The gas filter is a vertical pressure vessel with internal filter elements.

11.3.2.3.11 Release Isolation Valve

The waste gas processing system release isolation valve is a motor-operated valve located downstream of reducing station 3. It is the last active component in the gaseous waste processing system upstream of the nuclear auxiliary building ventilation system.

11.3.2.3.12 Release Radiation Sensor

The waste gas processing system release radiation sensor is located downstream of the release isolation valve, and monitors the activity of processed waste gas that is released to the nuclear auxiliary building ventilation system.

11.3.2.3.13 Measuring Gas Compressors

The measuring gas compressors draw batch gas samples from the purge gas process stream for analysis of the hydrogen and oxygen concentrations in the purge gas. The measuring gas compressors are double diaphragm compressors; the first diaphragm compresses the gas, and the second diaphragm provides a gas-tight seal in the event of a working membrane failure. A negative pressure is maintained between the two membranes and is monitored and alarmed to detect possible membrane failure.

11.3.2.3.14 Measuring Gas Drier

The measuring gas driers remove moisture from the sample gas by condensation. The measuring gas driers are stainless steel tubes that use a refrigeration cycle to cool the sample gas. Each measuring circuit upstream and downstream of the recombiner has one measuring gas drier capable of cooling the total measuring gas flow delivered by the measuring gas compressors.

11.3.2.3.15 Measurement Cabinets

The measurement cabinets are gas analyzers that measure the concentration of hydrogen and oxygen in the sample of purge gas cooled by the measuring gas drier. The measuring circuit upstream of the recombiner has two measurement cabinets configured in parallel; the downstream measuring circuit has a single measurement cabinet. Each measurement cabinet contains one hydrogen sensor and one oxygen sensor. The hydrogen sensors and oxygen sensors in the upstream measurement cabinets each signal several different interlocks. The sensors provide a control signal that varies the position of the hydrogen and oxygen supply gas control valves to adjust the ratio of gases in the influent to the recombiner. Each sensor has an interlock with the hydrogen and oxygen supply gas quick-closing isolation valves to isolate these supplies of potentially explosive gases from the gaseous waste processing system. Each sensor also has an interlock with isolation valves from, or nitrogen blanket supply valves to, those connected components that are major sources of hydrogen (e.g., pressurizer relief tank, reactor coolant drain tank, coolant degasification system). Finally, each sensor has an interlock to shut down the recombiner. Each sensor also generates two warning signals, corresponding to the “high” and “high-high” setpoints for hydrogen or oxygen concentration. These signals annunciate both locally and in the main control room. The interlocks actuate when the hydrogen concentration exceeds four percent by volume, or when the oxygen concentration exceeds two percent by volume.

No additional sources of hydrogen or oxygen enter between the upstream and downstream measurement cabinets and the catalyst in the recombiner combines the hydrogen and oxygen gases present into water vapor. Consequently, only one measurement cabinet is required downstream of the recombiner. The hydrogen and oxygen sensors in that cabinet have only indication and warning functions.

11.3.2.3.16 Condensate Collecting Tank

The condensate collecting tank collects the liquid formed by condensation in the pre-drier. This tank drains to the NI drain and vent system primary effluent tank in the Fuel Building. The condensate collecting tank is a cylindrical, stainless steel pressure vessel.

11.3.2.3.17 Sealing Liquid Coolers

The sealing liquid coolers reduce the temperature of the circulating sealing liquid before it returns to the waste gas compressors. The sealing liquid must be cooled to avoid evaporation in the subatmospheric pressure conditions prevailing at the waste gas compressor intake. If not controlled, sealing liquid evaporation can reduce the integrity of the waste gas compressor seals and lead to a reduced operating life for the waste gas compressors. The sealing liquid coolers are stainless steel shell and tube heat exchangers. The operational chilled water system provides cooling liquid flow to the tube bundle in the sealing liquid coolers.

11.3.2.3.18 Containment Isolation Valves

Containment isolation valves isolate the gaseous waste processing system from the pressurizer relief tank and the reactor coolant drain tank. These valves are located on the gaseous waste processing supply and return piping at the respective penetrations from the Fuel Building into the Reactor Building. The valves are normally open to allow purge gas flow through the tanks, but are automatically closed by a containment isolation signal to prevent the potential release of radioactive material from the Reactor Building. The containment isolation valves and the intervening piping at each penetration are safety related.

11.3.2.3.19 Bypass Valves

The recombiner and gas cooler may be isolated and bypassed in response to certain abnormal operating conditions. Under these conditions, two normally open air-operated isolation valves are closed to isolate the recombiner from the gaseous waste processing flow path, while the normally closed air-operated bypass valve is opened to provide an alternate system flow path.

If gaseous waste processing system conditions require, the waste gas compressors may be isolated and bypassed to establish a nitrogen blanket on connected components. In this case, two normally open motor-operated isolation valves are closed to remove both waste gas compressors from the gaseous waste process flow, and a motor-operated valve is opened to provide an alternate system flow path.

The first delay bed may be isolated and bypassed if water intrusion reduces the adsorptive capability of the activated charcoal. The two normally open delay bed isolation valves are closed to remove the first delay bed from gaseous waste processing delay system flow path, and the normally closed delay bed bypass valve is opened to provide an alternate delay system flow path to the second delay bed.

11.3.2.3.20 Materials

The components and piping of the gaseous waste processing system are made of stainless steel. Austenitic stainless steel is used for components and piping subject to higher levels of chlorides, such as the recombiner.

11.3.2.4 Failure Tolerance

The gaseous waste processing system incorporates features that make it more resistant to, or tolerant of, system faults and operator errors.

11.3.2.4.1 Hydrogen Ignition

The gaseous waste processing system prevents hydrogen ignition in the purge gas return system and in the connected components by maintaining a continuous flow of nitrogen purge gas through connected components. This purge gas flow sweeps out the hydrogen present in the gaseous waste processing return line before the hydrogen can accumulate in potentially explosive concentrations. The aggregate gaseous waste processing return stream is continually monitored for hydrogen and oxygen concentration, and the upstream measurement cabinets send signals to the gas supply subsystems to provide batch hydrogen or oxygen additions as necessary to maintain a stoichiometric ratio for recombination, as well as to inject nitrogen if necessary to dilute the hydrogen, or oxygen, concentration. The recombiner uses a catalytic process that recombines hydrogen and oxygen to form water vapor, which is removed from the gaseous waste processing purge flow downstream of the waste gas compressor. In addition to the automatic control signals, alarms are generated in the main control room if excessive hydrogen or oxygen concentrations are detected upstream or downstream of the recombiner. The nitrogen gas supply system can also inject a nitrogen blanket on some connected components if there is an interruption in gaseous waste processing purge flow.

11.3.2.4.2 Fire in Delay Beds

The system design precludes a fire in the delay beds because the recombination process reduces the oxygen content in the purge flow downstream of the recombiner. Under normal conditions, only a small fraction of that purge flow is diverted to the delay system. In the event that oxygen is transferred into the activated charcoal columns of the delay beds, the temperature inside the delay beds is normally below the auto-ignition temperature; temperature sensors for each delay bed provide indication in the main control room that this condition is maintained. In the hypothetical event of a fire in the delay beds, they can be isolated from the gaseous waste processing purge gas flow, and nitrogen can be directly injected from the nitrogen gas supply system to extinguish the fire.

11.3.2.4.3 Water Incursion

Several operations in the gaseous waste processing system prevent water incursion into the delay beds. Moisture entrained in the purge gas flow returning from connected components is removed by condensation in the gas drier. Additional moisture generated by the recombination of hydrogen and oxygen is condensed by the gas cooler for removal downstream in the sealing liquid tank. Sealing water that is entrained in the discharge from the waste gas compressor is separated from the purge gas in the sealing liquid tank. The pre-drier removes moisture from the purge gas supply flow by condensation. The gas drier, gas cooler, sealing liquid tank, and pre-drier are physically located at relative low points in the system piping, so they serve as collection points for water in the system. Finally, in normal system operation, expansion through reducing station 1 also dries the purge gas flow. During surge gas operation, the drying effects of expansion are lost, but the surge gas flow is routed through the gel drier, which is designed to dry the full surge gas flow into the delay system.

11.3.2.4.4 Nitrogen Blanket

During normal plant operation, connected components in the RCS continuously deliver hydrogen to the gaseous waste processing system. If both waste gas compressors fail or if the recombiner must be bypassed, the connected components in the RCS and the gaseous waste processing purge gas return line must be blanketed with nitrogen to prevent the ingress of atmospheric oxygen and the formation of a potentially explosive mixture.

Recombiner outage can be caused by shutdown of both waste gas compressors, by reversible or irreversible precipitation of media onto the catalyst, and by excessive deviations in the hydrogen or oxygen measurements between the two upstream measurement cabinets. Reversible precipitation can be caused by water intrusion. In addition to the measures described in Section 11.3.2.3.6, the recombiner is protected from water intrusion by a ball-type float valve downstream of the gas drier, and by the heating elements that prevent moisture from precipitating even at low hydrogen concentrations and low rates of exothermal heating by the chemical reaction. Irreversible precipitation on the recombiner catalyst could arise from mixtures of sulphur, phosphorous, arsenic, or oil, but these materials do not enter the gaseous waste processing system under normal plant operating conditions.

Excessive deviations in hydrogen or oxygen measurements, or recombiner outage due to precipitation, result in a changeover to recombiner bypass operation. In this case, purge gas flow is directed around the recombiner and gas cooler, and the nitrogen gas supply system provides nitrogen to blanket connected components, such as the pressurizer relief tank and the volume control tank, that are sources of hydrogen which cannot be immediately shut down or isolated.

11.3.2.4.5 Hydrogen/Oxygen Measurement Circuit Failures

The gaseous waste processing system is protected from failures of the upstream hydrogen and oxygen measurement circuit in several ways. The upstream measuring circuit includes one installed spare measuring gas compressor, which can replace either of the two operating measuring gas compressors. Failure of the measuring gas drier is indicated by temperature measurements, which annunciate an alarm in the main control room. Because the loss of the upstream measuring gas drier only affects measurement accuracy, no interlocks are invoked; the downstream measuring gas drier may temporarily replace the failed measuring gas drier until a permanent replacement is installed. Malfunctions to either gas sensor in either of the measurement cabinets of the upstream measurement circuit are indicated by sensor currents outside a predetermined range. These malfunctions annunciate an alarm in the main control room, and simultaneously send a signal that closes the injection valves and the quick-closing isolation valve of both the hydrogen and the oxygen gas supplies to immediately stop hydrogen and oxygen injection. The downstream measurement circuit is used to monitor recombiner performance; however the limiting hydrogen and oxygen concentrations are observed upstream of the recombiner.

11.3.2.4.6 Hydrogen or Oxygen Supply Control Valve Failure

The gaseous waste processing system includes redundant hydrogen and oxygen gas supply control valves so that a failure to one control valve does not prevent injection of either gas. These control valves also are subject to several interlocks. The control valves are equipped with mechanical stroke limitations so that supply gas injection does not cause flammable concentrations in the gaseous waste processing system. Additionally, each gas supply is equipped with an air-operated, quick-closing, isolation valve that also responds to interlocks to stop the injection of hydrogen and oxygen.

11.3.2.4.7 Redundant Components

The gaseous waste processing system incorporates redundant components to enhance system tolerance to single component failures. Redundant components include:

- Waste gas compressors and their respective sealing liquid subsystems.
- Control and isolation valves at reducing stations 1, 2, 3, 6, and 7.
- Control and isolation valves in the hydrogen and oxygen gas supply systems.
- Containment isolation valves.
- Installed spare measuring gas compressors in the upstream and downstream gas measuring circuits.

Additional redundancy is provided by pairing sensors to monitor key system parameters because each individual sensor in these pairs can generate signals to actuate controls, alarms, and interlocks.

11.3.2.5 Inspection and Testing Requirements

11.3.2.5.1 Preoperational Testing

The U.S. EPR gaseous waste processing system incorporates a number of features that are subject to performance validation by preoperational testing. Preoperational testing examines proper detection of setpoints by the relevant sensors, as well as proper response by system components for the following components and functions:

- Control functions at each of the nine reducing stations.
- Gas supply system control valves and quick-closing isolation valves.
- Delay system discharge isolation valve.
- Recombiner operation (tested to demonstrate efficient recombination of hydrogen and oxygen).
- Upstream and downstream measuring circuits (tested for accurate measurements of hydrogen and oxygen concentrations in samples of known gas mixtures).
- Waste gas compressor compression ratios.
- Pressure integrity of gaseous waste processing system piping and components (tested to demonstrate that the positive pressure portions of the system remain intact for pressure transients expected during system operation).
- Containment ventilation system and nuclear auxiliary ventilation system air filtration and adsorption units (tested to validate performance).

11.3.2.5.2 Preoperational Inspection

The U.S. EPR gaseous waste processing system incorporates several features subject to performance validation by preoperational inspection. Leak tightness and leak rates associated with different sections of the system are inspected during the pressure integrity test to confirm that in-leakage of air or out-leakage of potentially radioactive gases meets specifications. Adsorbent media loads in the gel drier and delay beds are inspected to confirm that sufficient media to achieve desired minimum performance are available.

11.3.3 Radioactive Effluent Releases

For the U.S. EPR, releases of radioactive effluent via atmospheric pathways occur due to:

- Gaseous waste processing system discharges.
- Containment ventilation discharges that contain activity as a result of reactor coolant leakage and as a result of the activation of naturally occurring argon-40 in the atmosphere to form argon-41.
- Ventilation discharges from the Safeguard Building controlled area ventilation, Fuel Building ventilation, radioactive waste processing building ventilation or nuclear auxiliary building ventilation systems, which contain activity because of leakage from process streams.

Iodine released in the coolant degasification system is removed from the gas mixture in the sealing liquid circuit of the degasifier pump. The same process occurs in the pre-drier, gas drier and gas cooler in the gaseous waste processing system, and also in the sealing liquid circuit of the waste gas compressors. Thus, iodine is not a significant constituent of the fission product gases treated in the gaseous waste processing system.

The steam generator blowdown and steam generator blowdown sampling systems are described in Section 10.4.8. Main condenser evacuation by the air removal system is described in Section 10.4.2. Turbine gland seals provided by the gland steam system are described in Section 10.4.3.

11.3.3.1 Discharge Requirements

Discharge requirements consist of gaseous waste activity, flow monitor alarm settings, and automatic isolation settings. These requirements are established for gaseous releases to meet the ALARA design objectives.

11.3.3.2 Estimated Annual Releases

The annual average airborne releases of radionuclides from the U.S. EPR are determined using the PWR-GALE code (Reference 1). The GALE code (Reference 1) models releases using realistic source terms derived from data obtained from the experience of many operating reactors, field and laboratory tests, and plant-specific design considerations incorporated to reduce the quantity of radioactive materials that may be released to the environment during normal operation, including AOOs. The code input values used in the analysis to model the U.S. EPR are provided in Table 11.2-3—Liquid and Gaseous Effluent Input Parameters for the GALE Computer Code. The expected annual releases for a single unit site are presented in Table 11.3-3—Gaseous Release (Ci/yr) Calculated by GALE Code.

11.3.3.3 Release Points

Gaseous effluents originating from the U.S. EPR are released at the top of the plant stack at an elevation of 211 ft above grade and approximately 100 ft above the top of the adjacent Fuel Building roof and 7 ft above the top of the Reactor. The inner diameter of the stack is approximately 12.5 ft at the point of release. In accordance with typical normal effluent modeling of releases, no elevated effluent temperatures are assumed. Effluent discharged from the delay system of the gaseous waste processing system is directed to the filtration system of the nuclear auxiliary building ventilation system. Exhaust air from the containment purge “full flow purge” (used only during plant outage periods and containment entries), along with exhaust air from the safeguard building controlled area ventilation, fuel building ventilation, radioactive waste processing building ventilation, and nuclear auxiliary building ventilation systems, is processed by the filtration system of the nuclear auxiliary building ventilation system before release from the stack. The combined flowrate of all the ventilation exhaust systems from the plant stack during normal operations that was used for gaseous effluent release evaluations was conservatively calculated to be approximately 242,500 cfm. The corresponding effluent exit velocity is approximately 1988 fpm during normal operations. The filtration system of the nuclear auxiliary building ventilation system continuously uses a prefilter and a HEPA filter. Iodine-adsorbent activated charcoal delay beds and a downstream HEPA filter are added to the flow path if radiation sensors in the stack detect elevated activity levels in exhaust gases. The containment purge "low flow purge" exhausts air from the Reactor Building through a dedicated filter path that includes two HEPA filters and an activated charcoal holdup bed into the nuclear auxiliary building ventilation system for discharge via the stack.

11.3.3.4 Estimated Doses

The GASPAR II computer program (Reference 2) was used to calculate doses to the maximally exposed individual (MEI) from gaseous releases. GASPAR II (Reference 2) implements the exposure methodology described in RG 1.109 for radioactive releases in gaseous effluent. The program considers the following exposure pathways:

- External exposure to contaminated ground.
- External exposure to noble gas radionuclides in the airborne plume.
- Inhalation of air.
- Ingestion of farm products grown in contaminated soil.

Inputs and assumptions are conservatively selected to represent a bounding condition for all dose pathways. The site boundary (where the MEI is assumed to reside for external exposure doses and inhalation doses) is assumed to be located at a distance of 0.5 miles from the reactor centerline. The dose receptors for the farm products (i.e., the nearest garden, nearest meat animal, and nearest milk animal) are also assumed to be located at a distance of 0.5 miles from the reactor centerline. The atmospheric dispersion and ground deposition factors are based on conservative values for a distance of 0.5 miles and a mixed-mode release from the plant stack. Inputs used by the GASPAR II code are presented in Table 11.3-4—Input Parameters for the GASPAR II Computer Code used in Calculating Annual Offsite Doses to the Maximally Exposed Individual from Gaseous Releases.

The U.S. EPR offsite dose to the MEI in an unrestricted area from gaseous effluent releases is presented in Table 11.3-5—Dose Commitment Due to Gaseous Effluent Releases. This table also compares these results to the limits specified in the 10 CFR Part 50 ALARA design objectives. U.S. EPR values are less than limiting values.

11.3.3.5 Maximum Release Concentrations

Using annual release data generated with the GALE code (Reference 1) and presented in Table 11.3-3, annual average concentrations of radioactive materials released in gaseous effluents to the discharge point have been determined. This analysis was based on an annual average atmospheric dispersion factor of 5.0E-06 sec/m^3. This value represents a conservative value for a distance of 0.5 miles from the reactor centerline, based on a mixed-mode release. For each radionuclide released, the average concentration has been compared to the limiting value for that radionuclide specified in 10 CFR Part 20, Appendix B Table 2. The results of this comparison are presented in Table 11.3-6—Comparison of Annual Average Gaseous Release Concentrations with 10 CFR Part 20 Concentration Limits. Average gaseous effluent concentrations for each radionuclide based on one percent failed fuel fraction have also been determined and compared to the limiting value for that radionuclide specified in 10 CFR Part 20, Appendix B, Table 2. The concentrations for the expected failed fuel case were upwardly adjusted by the ratio of design basis fuel failure primary coolant activity to expected fuel failure primary coolant activity, except for specific radionuclides in which Technical Specifications (TS) limit the maximum primary coolant activity. The results of the design basis case are also presented in Table 11.3-6. For both normal and maximum defined fuel failure cases, individual site boundary concentrations for the U.S. EPR are less than the applicable limits specified in 10 CFR Part 20, Appendix B, Table 2.

11.3.3.6 Radioactive Gaseous Waste System Leak or Failure

In the event of an operator error leading to an inadvertent bypass of the gaseous waste system delay bed, the exhaust from the coolant degasification system is released directly to the environment. Based on a one-hour release to the environment, the exposure at the exclusion area boundary is less than 0.1 rem, in accordance with BTP 11-5 (Reference 3).

11.3.3.7 Quality Assurance

The quality assurance program governing design, fabrication, procurement, and installation of the gaseous waste processing system meets the requirements of RG 1.143 as described in Chapter 17. For the containment isolation valves and associated piping, the quality assurance program meets the requirements of Appendix B to 10 CFR Part 50 and Section III-ND of the ASME Boiler and Pressure Vessel Code (Reference 4).

11.3.4 Gaseous Waste Management System Cost-Benefit Analysis

10 CFR Part 50, Appendix I requires that plant designs consider additional items based on a cost-benefit analysis. Specifically, the design must include all items of reasonably demonstrated cleanup technology that, when added to the gaseous waste processing

system sequentially and in order of diminishing cost-benefit return, can, at a favorable cost-benefit ratio, reduce the dose to the population reasonably expected to be within 50 miles of the reactor. The cost-benefit analysis presented in this section is for a typical site and results demonstrate that additional cleanup technology is not warranted. Additionally, the U.S. EPR incorporates by reference NEI 07-11, Generic FSAR Template Guidance for Cost-Benefit Analysis for Radwaste Systems for Light-Water Cooled Nuclear Power Reactors (Reference 5). This reference independently demonstrates compliance with 10 CFR Part 50, Appendix I, Section II.D.

The next logical gaseous waste processing component for the U.S. EPR is the addition of a charcoal delay bed to the waste gas holdup subsystem. The original design contains three delay bed vessels, and the augmented design contains four delay bed vessels. All other features and parameters of the system are assumed to remain the same.

11.3.4.1 Calculation of Population Doses

The source term for each equipment equipment configuration option in this analysis was generated using the NUREG-0017 GALE code (Reference 1) and system parameters from Table 11.2-3. All input parameters to the GALE code (Reference 1) are the same for the base and augmented cases except for those parameters affected by the addition of a delay bed. The only GALE (Reference 1) input parameters affected by the design change are the holdup times for krypton and xenon. Holdup times are increased in proportion to the increase in mass of charcoal adsorber.

The GASPAR II code (Reference 2) was used to determine the population doses for both cases. Input parameters are given in Table 11.3-4. GASPAR II (Reference 2) input values for a typical site were used. These parameters include data within 50 miles of the reactor for population, meteorological dispersion, milk production, meat production, and vegetable production. Although entered by sector and distance for the actual analysis, total values for population and production data are provided in Table 11.3-4.

11.3.4.2 Dose Benefits and Augment Cost

The cost-benefit analysis uses a value of $2000 per person-rem as a favorable cost-benefit threshold based on NUREG-1530 (Reference 6). The cost basis for the equipment option is taken from RG 1.110 and reported in 1975 non-escalated dollars, which provides a conservatively low estimate of the equipment cost compared to present dollars. The analysis uses a 60-year operating period, since the U.S. EPR is designed for a 60-year operating life.

The dose reduction effects for the sequential addition of the next logical gaseous waste processing component (i.e., addition of a charcoal delay bed to the waste gas holdup subsystem) results in a reduction in the 50 mile population total body and thyroid dose of 0.03 person-rem. Table 11.3-8—Obtainable Dose Benefits for Gaseous Waste System Augment shows the population dose associated with both the base case equipment configuration and that associated with the augmented delay system. Table 11.3-8 also shows the dose benefit achieved from the augmented delay system. Table 11.3-9—Gas Waste Management Cost-Benefit Analysis compares the estimated total body and thyroid dose reduction or savings achieved with the addition of the extra delay bed along with a conservative estimated cost for the purchase of this equipment. Operating and maintenance (O&M) cost associated with this passive subsystem is negligible. The cost basis for the equipment option is taken from RG 1.110 and reported in 1975 non-escalated dollars which provides a conservatively low estimate of the equipment cost compared to present value.

Table 11.3-9 shows that the favorable benefit in reduced dose associated with the additional charcoal delay bed has a dollar equivalent benefit value of $3600. However, the estimated cost to purchase this equipment is conservatively (low) estimated as $67,000. This analysis results in a total body effective benefit to cost ratio of less than 1.0 (and therefore a gaseous waste system augment is not justified on an ALARA basis of dose savings to the public).

The sources of gaseous effluents to the environment include waste streams processed through the gaseous waste processing system, containment purge exhaust, condenser air ejector exhaust, and building ventilation exhaust from the Safeguard Building, Nuclear Auxiliary Building, Radioactive Waste Processing Building, and Fuel Building. The gaseous waste processing system is designed such that little activity is released to the environment. The gaseous effluent source term is based upon a specified amount of primary coolant leakage. Radioactivity in this leakage is released to the environment via the building ventilation systems. Unlike the effluents from the gaseous waste processing system, which have the opportunity to decay through the charcoal delay beds before being released, the building ventilation releases do not benefit from holdup. Therefore, these building ventilation waste streams contain a significantly higher amount of activity than releases from the gaseous waste processing system. As such, an augment to the gaseous waste processing system provides little reduction to the overall activity released from all sources of gaseous effluents.

An alternative analysis was performed in Section 11.2.4 to demonstrate the potential benefit of providing a hypothetical augment to the liquid waste processing system that could eliminate all activity. For liquid effluents, all liquid waste streams containing radioactivity are processed via the liquid waste processing system, and the resulting total release to the environment in the bounding case is reduced to zero. Since the releases from the gaseous waste processing system represent a relatively small percentage of the total gaseous releases to the environment, if an augment were available that could reduce to zero the amount of activity released from the gaseous waste processing system, the reduction realized has little benefit compared to the overall gaseous release. Thus an alternative analysis for the gaseous waste processing system has not been performed, since only a small percentage of total gaseous effluents released to the environment is affected by such an augment.

11.3.5 References

1. NUREG-0017, “Calculation of Releases of Radioactive Materials in Gaseous and Liquid Effluents from Pressurized Water Reactors PWR-GALE Code,” Revision 1, NRC, April 1985.
2. NUREG/CR-4653, “GASPAR II – Technical Reference and User Guide,” NRC, March 1987.
3. NUREG-0800, BTP 11-5, “Postulated Radioactive Releases Due To A Waste Gas System Leak or Failure,” Revision 3, NRC, March 2007.
4. ASME Boiler and Pressure Vessel Code, Section III, “Rules for Construction of Nuclear Facility Components,” The American Society of Mechanical Engineers, 2004.
5. NEI 07-11, “Generic FSAR Template Guidance for Cost-Benefit Analysis for Radwaste Systems for Light-Water Cooled Nuclear Power Reactors,” Revision 0, Nuclear Energy Institute, September 28, 2007.
6. NUREG-1530, “Reassessment of NRC’s Dollar Per Person-Rem Conversion Factor Policy,” NRC, December 1995.

Table 11.3-1—Gaseous Waste Processing System Parameters

Normal Operation Parameter	Value
Design pressure: waste gas compressors to reducing stations	0.2–315 psia
Design temperature: waste gas compressors to reducing stations	212°F
Design pressure: reducing stations to upstream measuring circuit	0.2–189 psia
Design temperature: reducing stations to upstream measuring circuit	212°F
Design pressure: recombiner to waste gas compressor	0.2–315 psia
Design temperature: recombiner to waste gas compressor	775°F
Design pressure: drying subsection	0.2–315 psia
Design temperature: drying subsection	400°F
Design pressure: delay line	0.2–315 psia
Design temperature: delay line	212°F
Design circulation flow	0.190 lbm/s
Design release flow	0.0765 lbm/s
Palladium based catalyst inventory in recombiner	308.7 lbm
Type I desiccant inventory in gel drier	121.3 lbm
Type II desiccant inventory in gel drier	33.1 lbm
Activated charcoal inventory per delay bed	5440 lbm
Xenon dynamic adsorption coefficient	70 cc/gm
Krypton dynamic adsorption coefficient	1160 cc/gm
Xenon holdup time	27.7 days
Krypton holdup time	40 hours

Table 11.3-2—Gaseous Waste Processing System Component Data
Sheet 1 of 4

Components / Parameters	Value
Sealing Liquid Tank	
Number	2
Type	Cylindrical pressure vessel
Design pressure	0.2–315 psia
Design temperature	212°F
Total volume	6.43 ft^3
Material	Austenitic stainless steel
Condensate Collecting Tank	
Number	1
Type	Cylindrical pressure vessel
Design pressure	0.2–189 psia
Design temperature	212°F
Total volume	0.78 ft^3
Material	Austenitic stainless steel
Waste Gas Compressor	
Number	2 (parallel)
Type	Liquid ring
Design pressure	0.2–315 psia
Design temperature	212°F
Design flow rate (@STP)	72.4 ft^3/min
Material	Austenitic stainless steel
Measuring Gas Compressor	
Number	5
Type	Double diaphragm
Design pressure	0.2–189 psia
Design temperature	212°F
Design flow rate	0.169 ft^3/min
Material	Austenitic stainless steel
Gas Drier	
Number	1
Type	Shell and tube
Design pressure (shell/tube)	0.2–189/240 psia

Table 11.3-2—Gaseous Waste Processing System Component Data
Sheet 2 of 4

Components / Parameters	Value
Design temperature (shell/tube)	212/115°F
Design flow rate (shell/tube)	0.190/3.307 lbm/s
Temperature inlet (shell/tube)	149/42.8°F
Temperature outlet (shell/tube)	104/53.6°F
Material	Austenitic stainless steel
Gas Cooler	
Number	1
Type	Shell and tube
Design pressure (shell/tube)	0.2–315/240 psia
Design temperature (shell/tube)	775/115°F
Design flow rate (shell/tube)	0.190/2.866 lbm/s
Temperature inlet (shell/tube)	662/42.8°F
Temperature outlet (shell/tube)	86/53.6°F
Material	Austenitic stainless steel
Sealing Liquid Coolers	
Number	2
Type	Shell and tube
Design pressure (shell/tube)	0.2–315/240 psia
Design temperature (shell/tube)	212/115°F
Design flow rate (shell/tube)	3.31/8.82 lbm/s
Temperature inlet (shell/tube)	104/42.8°F
Temperature outlet (shell/tube)	68/53.6°F
Material	Austenitic stainless steel
Pre-Drier	
Number	1
Type	Shell and tube
Design pressure (shell/tube)	0.2–315/240 psia
Design temperature (shell/tube)	212/115°F
Design flow rate (shell/tube)	0.190/0.49 lbm/s
Temperature inlet (shell/tube)	122/42.8°F
Temperature outlet (shell/tube)	50/53.6°F
Material	Austenitic stainless steel
Measuring Gas Drier	

Table 11.3-2—Gaseous Waste Processing System Component Data
Sheet 3 of 4

Components / Parameters	Value
Number	2
Type	Electric
Design pressure (shell/tube)	0.2–189/NA psia
Design temperature (shell/tube)	212/NA°F
Design flow rate (shell/tube)	0.0004/NA lbm/s
Temperature inlet (shell/tube)	122/NA°F
Temperature outlet (shell/tube)	41/NA°F
Material	Austenitic stainless steel
Recombiner	
Number	1
Type	Cylindrical pressure vessel
Design pressure	0.2–189 psia
Design temperature	775°F
Design flow rate	0.190 lbm/s
Total volume	9.89 ft^3
Gel Drier	
Number	1
Type	Cylindrical pressure vessel
Design pressure	0.2–315 psia
Design temperature	400°F
Design flow rate	0.190 lbm/s
Total volume	3.18 ft^3
Material	Austenitic stainless steel
Delay Beds	
Number	3 (sequential)
Type	Cylindrical pressure vessel
Design pressure	0.2–315 psia
Design temperature	212°F
Design flow rate	0.0765 lbm/s
Total volume each bed (actual/useable)	187/167.4 ft^3
Dew point	-40°F
Material	Austenitic stainless steel
Gas Filter	

Table 11.3-2—Gaseous Waste Processing System Component Data
Sheet 4 of 4

Components / Parameters	Value
Number	1
Type	Pressure vessel w/ filter elements
Design pressure	0.2–315 psia
Design temperature	212°F
Design flow rate	0.0765 lbm/s
Filter efficiency	99.99%

Table 11.3-3—Gaseous Release (Ci/yr) Calculated by GALE Code
Sheet 1 of 2

Nuclide	Gas Stripping (continuous)	Reactor	Auxiliary	Turbine	Air Ejector Exhaust	Total
Kr-85m	0.0E+00	1.4E+02	4.0E+00	0.0E+00	2.0E+00	1.5E+02
Kr-85	1.4E+04	1.6E+04	1.4E+02	0.0E+00	6.8E+01	3.4E+04
Kr-87	0.0E+00	4.7E+01	4.0E+00	0.0E+00	2.0E+00	5.3E+01
Kr-88	0.0E+00	1.7E+02	7.0E+00	0.0E+00	4.0E+00	1.8E+02
Xe-131m	4.9E+02	2.8E+03	2.6E+01	0.0E+00	1.2E+01	3.5E+03
Xe-133m	0.0E+00	1.8E+02	2.0E+00	0.0E+00	0.0E+00	1.8E+02
Xe-133	2.0E+02	8.2E+03	8.0E+01	0.0E+00	3.7E+01	8.6E+03
Xe-135m	0.0E+00	9.0E+00	3.0E+00	0.0E+00	2.0E+00	1.4E+01
Xe-135	0.0E+00	1.2E+03	2.3E+01	0.0E+00	1.1E+01	1.2E+03
Xe-137	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Xe-138	0.0E+00	8.0E+00	3.0E+00	0.0E+00	1.0E+00	1.2E+01
Nuclide	**Fuel Building**	**Reactor**	**Auxiliary**	**Turbine**	**Air Ejector Exhaust**	**Total**
I-131	2.7E-04	1.9E-03	6.6E-03	0.0E+00	0.0E+00	8.8E-03
I-133	1.0E-03	5.8E-03	2.5E-02	0.0E+00	0.0E+00	3.2E-02

Nuclide	Waste Gas System	Reactor	Auxiliary	Fuel Handling	Total
Cr-51	1.4E-07	9.2E-05	3.2E-06	1.8E-06	9.7E-05
Mn-54	2.1E-08	5.3E-05	7.8E-07	3.0E-06	5.7E-05
Co-57	0.0E+00	8.2E-06	0.0E+00	0.0E+00	8.2E-06
Co-58	8.7E-08	2.5E-04	1.9E-05	2.1E-04	4.8E-04
Co-60	1.4E-07	2.6E-05	5.1E-06	8.2E-05	1.1E-04
Fe-59	1.8E-08	2.7E-05	5.0E-07	0.0E+00	2.8E-05

Table 11.3-3—Gaseous Release (Ci/yr) Calculated by GALE Code
Sheet 2 of 2

Sr-89	4.4E-07	1.3E-04	7.5E-06	2.1E-05	1.6E-04
Sr-90	1.7E-07	5.2E-05	2.9E-06	8.0E-06	6.3E-05
Zr-95	4.8E-08	0.0E+00	1.0E-05	3.6E-08	1.0E-05
Nb-95	3.7E-08	1.8E-05	3.0E-07	2.4E-05	4.2E-05
Ru-103	3.2E-08	1.6E-05	2.3E-07	3.8E-07	1.7E-05
Ru-106	2.7E-08	0.0E+00	6.0E-08	6.9E-07	7.8E-07
Sb-125	0.0E+00	0.0E+00	3.9E-08	5.7E-07	6.1E-07
Cs-134	3.3E-07	2.5E-05	5.4E-06	1.7E-05	4.8E-05
Cs-136	5.3E-08	3.2E-05	4.8E-07	0.0E+00	3.3E-05
Cs-137	7.7E-07	5.5E-05	7.2E-06	2.7E-05	9.0E-05
Ba-140	2.3E-07	0.0E+00	4.0E-06	0.0E+00	4.2E-06
Ce-141	2.2E-08	1.3E-05	2.6E-07	4.4E-09	1.3E-05
H-3	N/A	N/A	N/A	N/A	1.8E+02
C-14	N/A	N/A	N/A	N/A	7.3E+00
Ar-41	N/A	N/A	N/A	N/A	3.4E+01

Note:

1. 0.0E+00 appearing in table indicates release is less than 1.0 Ci/yr for noble gases, less than 0.0001 Ci/yr for iodine.

Table 11.3-4—Input Parameters for the GASPAR II Computer Code used in Calculating Annual Offsite Doses to the Maximally Exposed Individual from Gaseous Releases

Parameter	Value
Source Term	GALE (Table 11.2-4, Total as Adjusted)
Distance to Reactor Centerline from:	
• Site Boundary	0.5 miles
• Nearest Vegetable Garden	0.5 miles
• Nearest Meat Animal	0.5 miles
• Nearest Milk Animal	0.5 miles
Milk Animal Considered	Goat (Note 1)
Annual Average Atmospheric Dispersion Factor	5.0E-06 sec/m^3
Annual Average Ground Deposition Factor	5.0E-08 m^{-2}

Notes:

1. Doses from goat milk consumption are higher than for cow milk consumption.
2. All other values are GASPAR II default values.

Table 11.3-5—Dose Commitment Due to Gaseous Effluent Releases

Type of Dose	U.S. EPR	10 CFR Part 50, Appendix I ALARA Design Objective
Beta Air Dose (mrad/yr)	13.3	20
Gamma Air Dose (mrad/y)	1.62	10
Total Body (mrem/y)	1.03	5
Skin (mrem/y)	9.76	15
Internal Organ (mrem/y)	9.9 (infant thyroid)	15

Table 11.3-6—Comparison of Annual Average Gaseous Release Concentrations with 10 CFR Part 20 Concentration Limits

Nuclide	Release Concentration (µCi/ml)[1]		10 CFR Part 20, Appendix B Concentration Limit (µCi/ml)
	Normal Releases	Maximum Fuel Defect	
H-3	2.85E-11	1.14E-10	1.00E-07
C-14	1.16E-12	1.16E-12	3.00E-09
Ar-41	5.39E-12	5.39E-12	1.00E-08
Cr-51	1.54E-17	1.54E-17	3.00E-08
Mn-54	9.04E-18	9.04E-18	1.00E-09
Co-57	1.30E-18	1.30E-18	9.00E-10
Co-58	7.61E-17	7.61E-17	1.00E-09
Co-60	1.74E-17	1.74E-17	5.00E-11
Fe-59	4.44E-18	4.44E-18	5.00E-10
Kr-85m	2.38E-11	6.71E-11	1.00E-07
Kr-85	5.39E-09	4.18E-09	7.00E-07
Kr-87	8.40E-12	1.47E-11	2.00E-08
Kr-88	2.85E-11	8.08E-11	9.00E-09
Sr-89	2.54E-17	2.54E-14	2.00E-10
Sr-90	9.99E-18	9.99E-15	6.00E-12
Zr-95	1.59E-18	1.59E-15	4.00E-10
Nb-95	6.66E-18	6.66E-15	2.00E-09
Ru-103	2.70E-18	2.70E-15	9.00E-10
Ru-106	1.24E-19	1.24E-16	2.00E-11
Sb-125	9.67E-20	9.67E-17	7.00E-10
I-131	1.40E-15	4.99E-14	2.00E-10
I-133	5.07E-15	8.33E-14	1.00E-09
Xe-131m	5.55E-10	5.00E-10	2.00E-06
Xe-133m	2.85E-11	4.26E-10	6.00E-07
Xe-133	1.36E-09	3.45E-08	5.00E-07
Xe-135m	2.22E-12	2.72E-12	4.00E-08
Xe-135	1.90E-10	5.99E-10	7.00E-08
Xe-137	0.00E+00	0.00E+00	1.00E-09
Xe-138	1.90E-12	2.02E-12	2.00E-08
Cs-134	7.61E-18	7.61E-15	2.00E-10
Cs-136	5.23E-18	5.23E-15	9.00E-10
Cs-137	1.43E-17	1.43E-14	2.00E-10
Ba-140	6.66E-19	6.66E-16	2.00E-09
Ce-141	2.06E-18	2.06E-15	8.00E-10

1. Release concentrations based on $\chi/Q = 5.0E\text{-}06\ s/m^3$.

Table 11.3-7—Input Parameters for the GASPAR II Computer Code used in Gaseous Waste Cost-Benefit Analysis

Parameter	Value
Source Term	GALE (Table 11.2-4, "Total as Adjusted")
50-Mile Population	8.1E+06
Production Data	
Cow Milk	2.3E+08 kg/yr
Meat	3.6E+07 kg/yr
Vegetable	1.7E+09 kg/yr
Fraction of Year that Animals are on Pasture	0.583
Average Humidity over Growing Season	8.4 g/m^3
Average Temperature over Growing Season	66.8 F
Atmospheric Dispersion Factors (highest 0.5 mile value)	3.2E-06 sec/m^3

Note:

1. All other values are GASPAR II default values.

Table 11.3-8—Obtainable Dose Benefits for Gaseous Waste System Augment

	Population Total Body Dose (Person-rem)	Population Thyroid Dose (Person-rem)
Baseline Configuration	5.52	5.80
Extra Carbon Delay Bed	5.49	5.77
Obtainable dose benefit by augment	0.03	0.03

Table 11.3-9—Gas Waste Management Cost-Benefit Analysis

Calculation	Whole Body/Thyroid Dose
Annual dose reduction to the population within 50 miles of site due to addition of a charcoal delay bed to the waste gas holdup subsystem	0.03 person-rem
Nominal dose over 60 years of operation	1.8 person-rem
Obtainable benefit from addition of charcoal delay bed	$3600
Total cost over 60 years of operation (direct cost + O&M×60 years)	$67,000
Benefit/Cost Ratio (values greater than 1.0 should be included in plant system design)	0.053