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 (GWPS) and other ventilation systems combine to form the gaseous waste management system (GWMS). 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 9.4.1.1, 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 as low as reasonably achievable (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.

Calculations of doses and radioactive releases are performed consistent with the methodologies of SRP Section 11.3, BTP-11-5 and of Regulatory Guides 1.109, 1.111, and 1.112.

The GWMS is designed in compliance with the regulatory position contained in RG 1.140 as it pertains to the design, testing, and maintenance of normal ventilation exhaust system air filtration and adsorption units. Further description of the U.S. EPR design as it relates to RG 1.140 can be found in Section 9.4.

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. The GWMS design also incorporates features consistent with the applicable guidance of RG 4.21 and which address NRC concerns identified in IE-BL-80-10. 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. Table 3.2.2-1 provides the seismic design and other design classifications for components in the gaseous waste management system.

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 vent stack for release to the environment. Radiation detectors in the vent 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.

11.3.1.2.4 Mobile Systems

A COL applicant that references the U.S. EPR design certification and that chooses to install and operate mobile skid-mounted processing systems connected to permanently installed GWMS processing equipment will include plant and site-specific information describing how design features and implementation of operating procedures for the GWMS will address the requirements of 10 CFR Part 20.1406(b) and guidance of SRP Section 11.3, RG 4.21, RG, 1.143, IE Bulletin 80-10, and NEI 08-08.

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 vent 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. 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.

Refer to Section 12.3.6.5.4 for radioactive waste management system design features which demonstrate compliance with the requirements of 10 CFR 20.1406.

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. In the event that the gel drier inventory is damaged, the gel can be removed and replaced. Spent desiccant can be processed by the solid waste management system (SWMS) in accordance with a plant-specific process control program (PCP).

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. Though the delay beds are protected from water and chemical contamination due to their physical location and protective interlocks, provisions to remove and replace spent charcoal are included in the vessel design. Spent charcoal can be processed by the SWMS in accordance with a plant-specific PCP.

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 contain non-sparking 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. The hydrogen and oxygen gas analyzers will have daily sensor checks, monthly functional checks, and quarterly calibrations.

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.

An equipment malfunction analysis is presented in Table 11.3-10. The analysis was performed in accordance with SRP Section 11.3 and BTP 11.5, and the results comply with the acceptance criteria of SRP Section 11.3 and BTP 11-5.

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 vent stack at an elevation of 212 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 vent 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 vent stack. The combined flowrate of all the ventilation exhaust systems from the vent 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 vent 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 vent stack.

A COL applicant that references the U.S. EPR design certification will provide a discussion of the onsite vent stack design parameters and site-specific release point characteristics.

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 vent 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 detailed dose commitment results by age group and organ due to gaseous effluent releases are provided in Table 11.3-11—Detailed Dose Commitment Results by Age Group and Organ due to Gaseous Effluent Releases. A summary of 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.

A COL applicant that references the U.S. EPR design certification will confirm that the site-specific parameters are bounded by those provided in Table 11.3-4 and the dose pathways provided in Section 11.3.3.4. For site-specific parameters that are not bounded by the values provided in Table 11.3-4 and dose pathways other than those provided in Section 11.3.3.4, a COL applicant that references the U.S. EPR design certification will perform a site-specific gaseous pathway dose analysis following the guidance provided in RG 1.109 and RG 1.111, and compare the doses to the numerical design objectives of 10 CFR Part 50, Appendix I and demonstrate compliance with requirements of 10 CFR Part 20.1302 and 40 CFR Part 190.

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. For the annual average radionuclide release concentrations for expected releases, the overall fraction of the effluent concentration limit is 0.02, which is well below the allowable value of 1.0.

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 a multiplication factor. For noble gases and iodine isotopes, the multiplication factor is the ratio of the primary coolant activity for the maximum expected fuel failure to the expected primary coolant activity. The maximum primary coolant activity for noble gases and iodine isotopes is controlled by Technical Specifications (TS). Corrosion products are not affected by the percentage of fuel defects and do not need a multiplication factor. Similarly, Carbon-14 and Argon-41 release rates are also independent of fuel defect level. Tritium is adjusted using the ratio of the primary coolant activity for maximum failed fuel defect (1 percent failed fuel) to expected primary coolant concentration. The release rate for all other isotopes is conservatively adjusted upward by a factor of 1,000. The results of the design basis case are also presented in Table 11.3-6. For the annual average radionuclide release concentrations for design basis (one percent failed fuel) releases, the overall fraction of the effluent concentration limit is 0.10, which is well below the allowable value of 1.0.

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.

A COL applicant that references the U.S. EPR design certification will confirm that the site-specific annual average gaseous effluent concentrations are bounded by those specified in Table 11.3-6. For site-specific annual average gaseous effluent concentrations that exceed the values provided in Table 11.3-6, a COL applicant that references the U.S. EPR design certification will demonstrate that the annual average gaseous effluent concentrations for expected and design basis conditions meet the limits of 10 CFR Part 20, Appendix B, Table 2 in unrestricted areas.

11.3.3.6 Radioactive Gaseous Waste System Leak or Failure

The purge system of the gaseous waste processing system operates at sub-atmospheric pressures, thus preventing leakage from the purge section to the building atmosphere. The positive pressure section of the system is designed to be leak tight, thus limiting the potential for leakage. The leak tightness of the system is verified by pre-operational testing as described in Section 11.3.2.5.2.

The gaseous waste processing system is capable of detecting leaks by monitoring the system operating parameters for abnormalities. For example, if a leak were to exist in the purge section of the system. the upstream O_2 instrument would detect a higher than normal oxygen concentration due to building air ingress. If a leak were to exist in the positive pressure section, the system instrumentation would indicate flow rates and pressures outside the normal operating range. Once identified through system instrumentation and controls (I&C), the operator can take appropriate action to isolate the leak.

A bounding analysis was performed for the hypothetical event where an operator error leads to an inadvertent bypass of the delay beds and 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). The scenario and associated assumptions and parameters used in the radiological evaluation are as follows:

- Inadvertent valve misalignment leads to direct exhaust of the degasification system to the atmosphere, via the auxiliary building ventilation system, until the misalignment is recognized and isolated. This condition is unlikely because of the alarms and mechanical interlocks used to prevent the simultaneous opening of both atmospheric release pathways (i.e., auxiliary building ventilation system and gaseous waste processing system). Also, alarms are provided in the event that the gaseous waste processing system valve to the degasification system vacuum pump discharge is open and the auxiliary building ventilation system release pathway is open. This event alerts the operator that the system is misaligned. In addition, there is a radiation monitor in the auxiliary building ventilation system exhaust that alerts MCR operators of the discharge of radioactive gas.
- The RCS noble-gas concentration is at 230 DE Xe-133 μCi/g, based on the minimum RCS degasification flow rate of 10 kg/second (79365 lbm/hr). This

concentration is about 10 percent higher than the TS limit of 210 DE Xe-133 μCi/g (see Table 11.1-2 for the individual radionuclide concentrations), which was also based on 10 kg/second degasification rate.

- The RCS degasification flow rate is then increased to 20 kg/second (158730 lbm/hr, the upper range for normal operation), at which time the valve-misalignment error is assumed to take place. Noble-gas injection into the RCS from fuel defects is assumed to continue.
- Ensuing release to the atmosphere is assumed to be direct, continuous, and unabated. The release is terminated one hour after the incident as a result of the automatic alarm in the MCR and operator action (an assumed conservative interval that is twice as long as the typical time allocated for such applications).
- Atmospheric dispersion factor at the receptor of interest (at the EAB) is 1.0E-03 seconds/m^3 (Table 2.1-1).
- Ensuing dose is computed by considering each individual noble-gas isotope in the release, along with the corresponding dose conversion factors in Federal Guidance Report 12 for submersion in a semi-infinite medium.

A COL applicant that references the U.S. EPR design certification will confirm that the site-specific accident atmospheric dispersion data is bounded by the values provided in Table 2.1-1. For site-specific accident atmospheric dispersion data that exceed the values provided in Table 2.1-1, a COL applicant that references the U.S. EPR design certification will provide a site-specific analysis demonstrating that the resulting dose at the exclusion area boundary associated with a radioactive release due to gaseous waste system leak or failure does not exceed 0.1 rem in accordance with SRP Section 11.3, BTP 11-5.

11.3.3.7 Quality Assurance

The quality assurance program governing the design of the gaseous waste management system conforms to ANSI/ANS 55.4-1993 Section 4.3 (Reference 6), and Regulatory Guide 1.143 Section 7 as indicated in Table 3.2.2-1. Implementation of the quality assurance as it relates to design is described in Chapter 17. The COL applicant is responsible for quality assurance requirements related to the system procurer and the system constructor. 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. A COL applicant that references the U.S. EPR design certification will perform a site-specific gaseous waste management system cost-benefit analysis.

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, U.S. Nuclear Regulatory Commission, April 1985.

2. NUREG/CR-4653, "GASPAR II – Technical Reference and User Guide," U.S. Nuclear Regulatory Commission, March 1987.

3. NUREG-0800, BTP 11-5, "Postulated Radioactive Releases Due To A Waste Gas System Leak or Failure," Revision 3, U.S. Nuclear Regulatory Commission, 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. Deleted.

6. ANSI/ANS-55.4-1993, R2007 (R=Reaffirmed): "Gaseous Radioactive Waste Processing Systems for Light Water Reactor Plants," American National Standards Institute/American Nuclear Society, 2007.

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 lb_m/s
Design release flow	0.0765 lb_m/s
Palladium based catalyst inventory in recombiner	308.7 lb_m
Type I desiccant inventory in gel drier	121.3 lb_m
Type II desiccant inventory in gel drier	33.1 lb_m
Activated charcoal inventory per delay bed	5440 lb_m
Xenon dynamic adsorption coefficient	1160 cc/gm
Krypton dynamic adsorption coefficient	70 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	Nominal 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
Design temperature (shell/tube)	212/115°F

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

Components / Parameters	Nominal Value
Design flow rate (shell/tube)	0.190/3.307 lb_m/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 lb_m/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 lb_m/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 lb_m/s
Temperature inlet (shell/tube)	122/42.8°F
Temperature outlet (shell/tube)	50/53.6°F
Material	Austenitic stainless steel
Measuring Gas Drier	
Number	2

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

Components / Parameters	Nominal Value
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 lb_m/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 lb_m/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 lb_m/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 lb_m/s
Total volume each bed (actual/usable)	187/167.4 ft^3
Dew point	-40°F
Material	Austenitic stainless steel

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

Components / Parameters	Nominal Value
Gas Filter	
Number	1
Type	Pressure vessel w/ filter elements
Design pressure	0.2–315 psia
Design temperature	212°F
Design flow rate	0.0765 lb_m/s
Filter efficiency	99.99%
Hydrogen Analyzer	
Number	3
Design pressure	189 psia
Design temperature	212°F
Design flow rate (upstream/downstream)[1]	0.0004/0.0002 lb_m/s
Oxygen Analyzer	
Number	3
Design pressure	189 psia
Design temperature	212°F
Design flow rate (upstream/downstream)[1]	0.0004/0.0002 lb_m/s
Radiation Monitor	
Number	2
Design pressure (upstream/downstream)[2]	315/15 psia
Design temperature (upstream/downstream)[2]	212/125°F
Design flow rate	0.0765 lb_m/s

Notes:

1. Upstream/downstream of the recombiner.
2. Upstream/downstream of the delay beds.

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

Nuclide	Gas Stripping (continuous)	Reactor	Auxiliary	Turbine	Air Ejector Exhaust	Total
Kr-85m	0.0E+00	1.5E+02	4.0E+00	0.0E+00	2.0E+00	1.6E+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	5.0E+01	4.0E+00	0.0E+00	2.0E+00	5.6E+01
Kr-88	0.0E+00	1.8E+02	7.0E+00	0.0E+00	4.0E+00	1.9E+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	1.9E+02	2.0E+00	0.0E+00	0.0E+00	1.9E+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	1.0E+01	3.0E+00	0.0E+00	2.0E+00	1.5E+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

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

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
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 11.3-3, Total as Adjusted)
Distance from Reactor Centerline to[1]:	
• Site Boundary	0.5 miles
• Nearest Vegetable Garden	0.5 miles
• Nearest Meat Animal	0.5 miles
• Nearest Milk Animal	0.5 miles
• Nearest Residence	0.5 miles
Milk Animal Considered	Goat[2]
Annual Average Atmospheric Dispersion Factor[3]	5.0E-06 s/m^3
Annual Average Ground Deposition Factor[3]	5.0E-08 m^{-2}

Notes:

1. The most conservative location was assumed for each of the applicable dose pathways.
2. Doses from goat milk consumption are higher than for cow milk consumption.
3. Conservative estimate based on a mixed-mode release.
4. All other values are GASPAR II default values. This includes the GASPAR II code parameter for the mid-point of reactor operation lifetime, which used the default value of 20 years even though the U.S. EPR is designed to operate for 60 years.

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)	1.65	10
Total Body (mrem/y)	1.05	5
Skin (mrem/y)	9.80	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	2.54E-11	7.15E-11	1.00E-07
Kr-85	5.39E-09	4.18E-09	7.00E-07
Kr-87	8.88E-12	1.55E-11	2.00E-08
Kr-88	3.01E-11	8.53E-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	3.01E-11	4.50E-10	6.00E-07
Xe-133	1.36E-09	3.45E-08	5.00E-07
Xe-135m	2.38E-12	2.91E-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

Note:

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

Table 11.3-7—Deleted

Table 11.3-8—Deleted

Table 11.3-9—Deleted

Table 11.3-10—Equipment Malfunction Analysis
Sheet 1 of 4

Equipment Item	Malfunction	Result(s)	Mitigating or Alternate Action(s)
Upstream radiation monitor	Fails to indicate.	Reading lost.	Upstream radiation monitor does not provide control functions. Manual grab sampling may be performed until monitor is repaired or replaced.
Downstream radiation monitor	Fails to indicate.	Reading lost. Failure of automatic isolation function.	Indication of activity is provided in the NABVS which can process waste gas through charcoal filters if activity is high. Grab sampling may be performed until monitor is repaired or replaced. Closure of release isolation valve may be controlled manually by operator.
Gel drier	Damage to desiccant.	Drying capability of gel drier is inhibited.	Gel drier can be isolated and desiccant replaced.
Delay beds	Delay bed is exposed to moisture. Delay bed performance gradually deteriorates and holdup of radioactive gases decreases.	Holdup of radioactive gases is inadequate. Plant emissions gradually increase.	Bypass first delay bed or isolate delay section. Dispose of spent charcoal and replace if necessary.
Condensate collecting tank level control	Level control of condensate collecting tank fails.	Level control of condensate collecting tank lost.	Delay section is isolated to prevent moisture carryover on high level, or drain valve is manually closed by operator on low level.
Sealing liquid tanks level control	Level control of sealing liquid tank fails.	Level control of sealing liquid tank lost.	Operator switches to alternate waste gas compressor train.

Table 11.3-10—Equipment Malfunction Analysis
Sheet 2 of 4

Equipment Item	Malfunction	Result(s)	Mitigating or Alternate Action(s)
Waste gas compressor	Waste gas compressor does not start or fails.	Temporary reduction in ability to sweep connected components. Dual compressor operation not possible.	Operator switches to alternate waste gas compressor train. System is designed to function adequately with one compressor in operation.
Upstream H_2/O_2 sensors	Fails to indicate.	Indication lost.	Operator switches control and indication to alternate measuring cabinet.
Downstream H_2/O_2 sensors	Fails to indicate.	Indication lost.	Manual grab sampling can be performed to monitor recombiner performance until measuring cabinet is repaired or replaced.
Upstream measuring gas compressor	Working diaphragm rupture.	Failure of measuring gas compressor.	Operator switches off affected compressor and starts redundant compressor. System operation continues.
Downstream measuring gas compressor	Working diaphragm rupture.	Failure of measuring gas compressor.	Operator switches off affected compressor and starts redundant compressor. System operation continues.
Upstream measuring gas drier	Failure of temperature control.	Inaccurate H_2/O_2 measurement.	Upstream measuring gas drier can be replaced with downstream measuring gas drier until drier is repaired or replaced. Grab sampling may be performed downstream.
Downstream measuring gas drier	Failure of temperature control.	Inaccurate H_2/O_2 measurement.	Manual grab sampling may be performed until measuring gas drier is repaired or replaced.

Table 11.3-10—Equipment Malfunction Analysis
Sheet 3 of 4

Equipment Item	Malfunction	Result(s)	Mitigating or Alternate Action(s)
Recombiner	Failure or temperature control.	Incomplete recombination of hydrogen and oxygen to water.	Malfunctioning heating element(s) switched off and replaced if necessary.
Gas cooler	Chilled water loss to cooler.	Inaccurate H_2/O_2 measurement. High humidity of waste gas.	Chilled water supply restored.
	Corrosion of tubes in cooler.	Leakage of water into process stream.	Plug tubes or replace cooler if there is considerable leakage.
Pre drier	Chilled water loss to drier.	Possible carryover of moisture to delay section.	Chilled water supply restored. Delay section is isolated if necessary.
	Corrosion of tubes in drier.	Leakage of water into process stream.	Plug tubes or replace cooler if there is considerable leakage. Delay section is isolated if necessary.
Gas drier	Chilled water loss to drier.	Inaccurate H_2/O_2 measurement.	Chilled water supply restored.
	Corrosion of tubes in drier.	Leakage of water into process stream.	Plug tubes or replace cooler if there is considerable leakage.
Sealing liquid coolers	Chilled water loss to cooler.	Inadequate cooling of sealing liquid to waste gas compressor.	Operator switches to alternate waste gas compressor train.
	Corrosion of tubes in drier.	Leakage of water into process stream.	Operator switches to alternate waste gas compressor train.
Nitrogen gas supply valve	Nitrogen gas supply valve fails open.	Pressure in purging section of GWPS increases.	Operator manually closes nitrogen gas supply valve. The recombiner if necessary.
Oxygen gas supply valves	Oxygen gas supply valve open during hydrogen injection.	Parallel addition of hydrogen and oxygen. Incomplete recombination and possible formation of explosive mixture.	Operator closes faulty supply valve and switches control to redundant valve.

Table 11.3-10—Equipment Malfunction Analysis
Sheet 4 of 4

Equipment Item	Malfunction	Result(s)	Mitigating or Alternate Action(s)
Hydrogen gas supply valves	Hydrogen gas supply valve open during hydrogen injection.	Parallel addition of hydrogen and oxygen. Incomplete recombination and possible formation of explosive mixture.	Operator closes faulty supply valve and switches control to redundant valve.
Instruments	Fails to indicate.	Indication lost.	Essential instruments are redundant or provided with one-out-of-two voting. Other instruments are replaceable.
Gaseous Waste Processing System Pressure Boundary	Failure of GWPS pressure boundary.	Waste gas released to equipment compartment/ environment.	In-leakage is detectable by oxygen and flow sensors. Most ruptures can be isolated by operator or automatic actions. Doses are within design guidance of BTP 11-5.
Fire in the delay beds	Higher than normal temperature/oxygen concentration in delay section causes fire in the delay beds.	Damage to activated carbon and reduced holdup of radioactive species.	Fire in the delay beds is precluded by the system design (see Section 11.3.2.4.2). However, if fire were to occur, the delay section could be isolated to prevent the release of waste gas and blanketed with nitrogen via the nitrogen gas supply system.

Table 11.3-11—Detailed Dose Commitment Results by Age Group and Organ due to Gaseous Effluent Releases[1]
Sheet 1 of 2

Pathway	Total Body (External Exposure)	Gi-Tract	Bone	Liver	Kidney	Thyroid	Lung	Skin (External Exposure)
	mrem/yr	mrem/yr	mrem/yr	mrem/yr	mrem/yr	mrem/yr	mrem/yr	mrem/yr
Plume	1.04E+00							9.79E+00
Ground	7.06E-03	7.06E-03	7.06E-03	7.06E-03	7.06E-03	7.06E-03	7.06E-03	8.28E-03
Vegetables								
Adult		2.52E-01	1.13E+00	2.51E-01	2.51E-01	1.03E+00	2.47E-01	
Teen		3.88E-01	1.82E+00	3.89E-01	3.89E-01	1.36E+00	3.82E-01	
Child		8.89E-01	4.33E+00	8.96E-01	8.95E-01	2.71E+00	8.85E-01	
Meat								
Adult		8.46E-02	3.90E-01	8.35E-02	8.34E-02	1.18E-01	8.31E-02	
Teen		6.97E-02	3.30E-01	6.92E-02	6.91E-02	9.39E-02	6.89E-02	
Child		1.28E-01	6.19E-01	1.28E-01	1.28E-01	1.65E-01	1.27E-01	
Cow Milk[2]								
Adult		9.86E-02	4.32E-01	1.02E-01	1.03E-01	1.07E+00	9.76E-02	
Teen		1.74E-01	7.96E-01	1.82E-01	1.83E-01	1.72E+00	1.73E-01	
Child		4.12E-01	1.95E+00	4.26E-01	4.28E-01	3.48E+00	4.11E-01	
Infant		8.45E-01	3.81E+00	8.78E-01	8.74E-01	8.31E+00	8.45E-01	
Goat Milk								
Adult		1.12E-01	4.41E-01	1.20E-01	1.19E-01	1.28E+00	1.11E-01	
Teen		1.92E-01	8.09E-01	2.07E-01	2.05E-01	2.05E+00	1.91E-01	
Child		4.39E-01	1.98E+00	4.67E-01	4.62E-01	4.12E+00	4.40E-01	

Table 11.3-11—Detailed Dose Commitment Results by Age Group and Organ due to Gaseous Effluent Releases[1]
Sheet 2 of 2

Pathway	Total Body (External Exposure)	Gi-Tract	Bone	Liver	Kidney	Thyroid	Lung	Skin (External Exposure)
Infant		8.86E-01	3.86E+00	9.47E-01	9.26E-01	9.84E+00	8.88E-01	
Inhalation								
Adult		2.06E-02	3.84E-04	2.06E-02	2.07E-02	4.80E-02	2.08E-02	
Teen		2.08E-02	4.67E-04	2.09E-02	2.10E-02	5.59E-02	2.12E-02	
Child		1.83E-02	5.70E-04	1.85E-02	1.86E-02	6.04E-02	1.87E-02	
Infant		1.05E-02	2.97E-04	1.07E-02	1.07E-02	4.92E-02	1.08E-02	
Totals[3]								
Adult	1.05E+00	4.76E-01	1.97E+00	4.82E-01	4.81E-01	2.48E+00	4.69E-01	9.80E+00
Teen	1.05E+00	6.78E-01	2.97E+00	6.93E-01	6.91E-01	3.57E+00	6.70E-01	9.80E+00
Child	1.05E+00	1.48E+00	6.94E+00	1.52E+00	1.51E+00	7.06E+00	1.48E+00	9.80E+00
Infant	1.05E+00	9.04E-01	3.87E+00	9.65E-01	9.44E-01	9.90E+00	9.06E-01	9.80E+00

Notes:

1. Doses represent the offsite dose to the maximally exposed individual (MEI) or nearest resident, who is assumed to reside at a distance of 0.5 miles from the reactor centerline.

2. The cow milk dose pathway is not included in the totals. The goat milk ingestion path is used instead because it results in a higher calculated dose.

3. Totals represent the external dose to total body, internal organ dose (from radioiodine, particulate, tritium, and C-14) and external dose to skin.

Next File