9.5 GASEOUS RADWASTE SYSTEM (Modified)

This subsection describes the Gaseous Radwaste System as it now exists with recombiners and activated carbon adsorbers installed in the condenser offgas system.

9.5.1 Power Generation Objective

The Gaseous Radwaste System collects and processes gaseous radioactive wastes from the main condenser air ejectors, the startup vacuum pumps, condensate drain tank vent, and the steam packing exhauster, and controls their release to the atmosphere through the plant stack so that the total radiation exposure to persons outside the controlled area is as low as reasonably achievable and does not exceed applicable regulations.

9.5.2 Power Generation Design Basis

1. The Gaseous Radwaste System is designed to limit offsite doses from routine plant releases to significantly less than the limits or guideline values given in applicable NRC rules and regulations, and to stay within the limits established in the plant operating license. The offgas system is designed to provide adequate time for corrective action to limit the activity release rates should they approach established limits.

2. Arrangements have been made to allow decay of the short-lived radioisotopes such as nitrogen-16 and oxygen-19.

3. Adequate safeguards have been provided against the possible explosion hazard of the hydrogen and oxygen present due to the radiolytic decomposition of reactor water.

4. Shielding has been provided as necessary for process piping and equipment.

9.5.3 Safety Design Basis

The Gaseous Radwaste System is designed to prevent the inadvertent release of significant quantities of gaseous and particulate radioactive material from the restricted area of the plant, so that resulting radiation exposures are within the guideline values of Appendix I of 10 CFR 50.

9.5.4 Description

The Gaseous Radwaste System (Figures 9.5-1 sheets 1, 2, 3, 4, 5, and 6, 9.5-2, 9.5-3, and 9.5-4) includes the subsystems that process and dispose of the gases from the main condenser air ejectors, the startup vacuum pumps, condensate drain tank vent, and the steam packing exhauster. One Gaseous Radwaste System is provided for each unit. The processed gases from Units 1, 2, and 3 are routed to the plant stack for dilution and elevated release to the atmosphere. The air ejector offgas line of each unit and the stack are continuously monitored by radiation monitors (see Subsection 7.12, "Process Radiation Monitoring").

Activities of activation gases and fission product gases leaving the reactor vessel steam nozzles during normal operation are listed in Table 9.5-1. The corresponding activity arriving at the turbine and air ejector will be less due to decay in transit and the fact that part of the N-13, N-16, and most of the 0-19 remain with the condensate and do not follow the noncondensables. Other radioactive gases which may also be present are H-3, N-17, Ar-37, and Ar-41. These are present in low enough quantities as to be insignificant by comparison with the N-13. Of the activity arriving in the primary steam at the turbine, a fraction will go through the turbine shaft steam seals to the gland seal offgas subsystem. Of this small fraction of the total activity, most of the 0-19 and N-16 will stay with the gland seal condensate.

Gases routed to the plant stack include air ejector and gland seal offgases and gases from the Standby Gas Treatment System (see Subsection 5.3, "Secondary Containment System"). Dilution air is provided by fans within the plant stack.

The stack is designed such that prompt mixing of all gas inlet streams occurs in the base to allow location of sample points as near to the base as possible. The stack sump drainage is routed to the Liquid Radwaste Collection System via a submerged inlet sump.

Air Ejector OffGas Subsystem

Noncondensable radioactive offgas is continuously removed from the main condenser by the air ejector during plant operation. This is the major source of radioactive gases and is larger than all other sources combined. The air ejector offgas will also contain the radioactive noble gas parents of biologically significant Sr-89, Sr-90, Ba-140, and Cs-137. The concentration of these noble gases depends upon the amount of tramp uranium in the coolant and on the cladding surface (usually extremely small), as well as the number and size of cladding leaks.

Radioactive particulate daughters are retained on the HEPA filters and on the activated carbon. The offgas is discharged to the environs via the plant stack. The activity of the gas entering and leaving the offgas treatment system is continuously monitored. Thus, the system performance is known to the operator at all times.

The air ejector offgas system shown in Figures 9.5-1 sheets 1, 2, 3, 4, 5, and 6 use a high temperature catalytic recombiner to recombine radiolytically dissociated hydrogen and oxygen from the air ejector system. After chilling to strip the condensibles and reduce the volume, the remaining noncondensables (principally kryptons, xenons and air) will be delayed in the six hour holdup volume, then cooled to ≈45°F (dewpoint) with a chilled glycol cooler passed through a moisture separation, heated to ≈74°F (relative humidity ≈35 percent), and passed through a HEPA filter before reaching the adsorption bed. The activated carbon adsorption bed, operating in a constant temperature vault, will selectively adsorb and delay the xenons and kryptons from the bulk carrier gas (principally air). This delay on the activated carbon permits xenon and krypton radioisotopes to decay in place. This system results in a reduction of the offgas activity (curies) released by a factor of approximately 25 relative to the original 30 minute holdup volume and based on a modified gas mixture. Table 9.5-1 shows the estimated release rates of various isotopes of krypton and xenon compared to a system releasing 100,000 μCi/sec after a 30 minute holdup.

The adsorption of noble gases on activated carbon depends upon gas flow rate, holdup time, mass of activated carbon, temperature, moisture content, and a gas-unique coefficient known as the dynamic adsorption coefficient. The parametric interrelationships and governing equations are well proven from three years of operation of a similar unit at KRB in Germany.

Each of the six supply lines from the adsorber vessels to the unloading nozzle drain is equipped with low point drains for minimization of moisture buildup.

As a design basis for this system, a noble gas input equivalent to an annual average off gas rate per unit (based on 30 minute decay) of 100,000 μCi/sec modified gas mixture will be used. Table 9.5-1 indicates the design-basis noble-gas activity referenced to 30 minutes after exiting from the reactor.

Air in-leakage, during normal operation, will vary with the performance of the equipment that forms the vacuum boundary for the condenser. The in-leakage rate is not a limiting factor in meeting the design basis of the system to minimize radioactive release. Release limits for the Offgas System are specified in the Offsite Dose Calculation Manual (ODCM). The Offgas System is designed to control the release of plant-produced radioactive material to within the limits specified in the ODCM.

The following data and discussion is maintained for historical reference. The information was used to estimate an 18.5 SCFM in-leakage rate for Browns Ferry prior to operation

Air in-leakage design basis is 7 ft^3/min. (at 130°F, 1 atm) per condenser shell. Leakage from three condenser shells corrected to standard conditions gives 18.5 SCFM, the original design leakage of the plant. With good-to-average maintenance within the utility industry, in-leakage varies from approximately 3 to 5 SCFM per shell for large shells. Where special maintenance is employed and leaks are detected and sealed, leakage is reduced to 1 to 2 SCFM per shell and remains at that level during extended plant operation.

In three operating BWRs where condenser in-leakage has a significant effect on offgas holdup time, the following leakage has been observed.

Plant	Mw(e)	Number of Condenser Shells	Type of Gas System	Total Air In-Leakage SCFM)
KRB	250	1	R/CG	4.1
Tsuruga	342	1	R/CG	4.7
Fukushima 1	440	2	R/CG	7.0

R/CG - Recombiner/Compressed Gas

Data from six of TVA's coal-fired units are given below:

Plant	Period	Mw(e)	Number of Condenser Shells	Air Rate Range	In-Leakage (SCFM) Average
Bull Run 1	4.5	950	4	5-48	14.5
Colbert 5	6.3	550	2	7-22	10.4
Paradise 1	7.6	704	1	2-14	5.6
Paradise 2	7.3	704	1	1-9	4.4
Widows Creek 7	9.2	575	1	2-18	8.8
Widows Creek 8	6.4	550	2	6-50	22.8

Period - Period covered by data in years

The average in-leakage for the first four of these units was below 6.2 SCFM per shell, while that for the last two units was above this value. Examination of operating records indicates that the latter units were allowed to operate for extended periods with high in-leakage rates.

Normally, no dilution air is added to the offgas stream, the air present during operation is from air in-leakage. There is an oil-free air supply which bleeds into the system during startup of the system. Its flow rate is ≈4 SCFM, which is stopped after the recombiner comes up to temperature. During times of low in-leakage, dilution air may be bled into the system to ensure minimum air flow rate for recombiner operation.

The radiation levels at the air ejector offgas discharge line and after the offgas treatment system are continuously monitored by pairs of detectors. This system is also monitored by flow and temperature instrumentation and hydrogen analyzers to ensure proper operation and control and to ensure that hydrogen concentration is maintained below the flammable limit. In addition, any hydrogen analyzer abnormality will be annunciated in the Main Control Room. Process radiation instrumentation is described in Subsection 7.12. Table 9.5-2 lists process instrument alarms.

The decay time provided by the six hour holdup pipe and the long-delay, activated carbon adsorbers is established to provide for radioactive decay of the activation gases and fission gases in the main condenser offgas. The adsorbers provide a 7.3 day xenon and a 9.7 hour krypton holdup. These holdup times may vary depending on offgas flow rates. The daughter products, which are solids, are removed by filtration following the six hour holdup and/or are retained on the activated carbon. Final filtration of the activated carbon adsorber effluent precludes escape of charcoal fines which would contain radioactive materials. Particulates are reduced to levels at or near the lower limits of detection. The activated carbon will remove iodines entering the system by adsorption and effectively reduce its release to insignificant amounts.

A valve which is automatically closed on a signal from the offgas post treatment radiation monitors is placed in the offgas line close to the plant stack to retain gases when the instantaneous permissible release rate is exceeded. A signal from both channels is required to close this valve when this release rate limit is reached. If the valve has been manually jacked open, it is manually closed after receipt of a validated pre-treatment radiation high-high alarm if necessary to prevent the release limit from being exceeded.

A steel mesh screen and support structure is installed downstream of the after-filters to ensure filter retention in the event of an explosion in the offgas system.

Shielding is provided for offgas system equipment to maintain safe radiation exposure levels for plant personnel. The equipment is principally operated from the control room.

A description of the condensate side of the offgas condensers is included in Section 11.8.3.6.

Gland Seal OffGas Subsystem

The gland seal offgas subsystem collects gases from the turbine shaft and large steam control valve gland seals through the steam packing exhauster and the mechanical vacuum pumps and passes them through holdup piping prior to release to the stack.

Gland seal offgases and gases from the mechanical vacuum pump, used during each startup and at "hot standby," are routed to the stack via the gland seal holdup line, which is separate from the air ejector holdup line.

The gland seal offgas subsystem provides a 1.75 minute holdup time to allow decay of N-16 and O-19. The holdup time is provided by a long, large diameter pipe between the steam packing exhauster and the stack. Operating and design pressure is atmospheric; no explosive mixture is present. No filters or radiation monitors are required in the holdup line. Release rates for the gland seal offgas subsystem are given in Table 9.5-7.

A valve between the main condenser and each mechanical vacuum pump is closed by a high radiation signal from the main steam line radiation detectors to isolate the mechanical vacuum pump from the main condenser. In addition, the mechanical vacuum pumps are automatically stopped by the same signal.

9.5.5 Safety Evaluation

The activated carbon adsorbers operate at essentially room temperature so that, upon system shutdown, radioactive gases in the adsorbers will be subject to the same holdup time as during normal operation, even in the presence of continued air flow. The radioactive materials are thus not subject to an accidental release evaluation. The activated carbon adsorbers are designed to limit the temperature of the activated carbon to well below its ignition temperature, thus precluding overheating or fire and consequent escape of radioactive materials. The adsorbers are located in a shielded room, maintained at a constant temperature by an air conditioning system which removes the decay heat generated in the adsorbers. Failure of the air conditioning system will cause an alarm in the control room. In addition, a radiation monitor is provided to monitor the radiation level in the activated carbon bed vault. High radiation will cause an alarm in the control room.

The hydrogen concentration of the gases from the air ejector is maintained below the flammable limit by maintaining adequate steam flow for dilution. The pressure of the steam supplied to the first and third stage steam jet air ejectors is monitored. The steam jet air ejector inlet and effluent are automatically isolated on low steam supply pressure. The preheaters are heated with steam, rather than electrically, to eliminate presence of potential ignition sources and to limit the temperature of the gases in the event of cessation of gas flow. The recombiner temperatures are monitored and an alarm is actuated to indicate any deterioration of performance. A hydrogen analyzer downstream of the recombiners provides an additional check on recombiner performance.

The air ejector offgas system operates at a pressure of about 5 psig or less, so the differential pressure which could cause leakage of radioactive gases is small. To minimize the possibility of leakage of radioactive gases, the system is welded wherever possible, and bellows seal valve stems or equivalent are used wherever possible.

Operational control is maintained by the use of radiation monitors to assure that the release rate is within the established limits. Environmental monitoring is used to determine resultant dose rates and to relate these to the release rates as a check on plant performance. Provision is also made for sampling and periodic analysis of the influent and effluent gases for purposes of determining their composition. This information can be used in comparisons and calibration of the monitors and in relating the release-to-environs dose.

Table 9.5-4 contains a detailed malfunction analysis indicating consequences of failure of various components of the system and design precautions taken to prevent such failures.

The air ejector offgas holdup pipe and the steam packing exhauster holdup pipe meet the requirements of USAS B31.1.0, Section 1 and Case N-12, with the exception that the stresses recommended by NACA-TN-3935 are acceptable as a minimum requirement. All piping and equipment added in connection with the activated carbon system are designed in accordance with the ASME Boiler and Pressure Vessel Code, Section III, Class 3, Nuclear Power Plant Components.

The inadvertent release of significant quantities of gaseous and particulate radioactive material is prevented by the combination of the air ejector offgas, six-hour holdup, activated-carbon adsorber, and the automatic isolation of the air ejector offgas subsystem from the stack by high-high-high radiation signals from the air ejector offgas post treatment monitors, or manual isolation based on a pre-treatment radiation monitor high-high alarm. In addition, the mechanical vacuum pumps are stopped and isolated from the condenser by a main steamline high radiation signal indicating gross fuel failure. It is therefore concluded that the safety design basis is met.

Table 9.5-5 is a list of the isotopic inventories of the equipment in the modified offgas system. This analysis was based upon the modified gas mixture source terms, holdup times calculated for the equipment, and postulated removal and holdup mechanism.

The bases for the calculations are given below:

1. 18.5 SCFM air in-leakage,

2. 100,000 μCi/sec NG modified gas mixture (λ^4) after 30 minute delay,

3. 6 activated carbon beds - 18 tons of activated carbon, and

4. Retention of daughter products by equipment:

   a. Offgas condenser - 100 percent but washed-out,

   b. Water separator - 100 percent but washed-out,

   c. Holdup pipe - 60 percent but washed-out,

   d. Prefilter - 100 percent,

   e. Carbon beds - 100 percent, and

   f. Post filter - 100 percent.

The assumptions generally give conservative daughter inventories or do not have a significant effect on daughter inventories. For example, 100 percent washout in the offgas condenser removes daughter products from the prefilter; but this represents less than one minute of delay compared to 360 minutes of delay experienced in the holdup pipe. Washout of 60 percent in the holdup pipe is conservative compared to 60 percent to 99 percent that has been measured in the EVESR facility at Vallecitos.

At Dresden 2, iodine activities were measured in the reactor water, condensate pump discharge, and offgas after being discharged from the 30 minute holdup pipe. An iodine reduction factor from the condensate (primary steam) to discharge of the holdup pipe was calculated. The following basis was used to calculate the iodine inventories shown in Table 9.5-5.

1. Standard plant iodine source terms at 100,000 μCi/sec NG at 30 minute decay for the reactor water;

2. Steam separation of 2 percent (reduction by a factor of 50 for iodine from the reactor water to the steam); and

3. Iodine reduction factor for primary steam to discharge of the holdup pipe as measured at Dresden 2.

Because of erratic removal of iodine by HEPA filters, the iodine inventory on the prefilter assumed 100 percent removal, while the inventory on the activated carbon assumed no removal by the prefilter.

The design approach for the system is to prevent/minimize an explosion, so that this is not considered as a failure mode. The following equipment failures are postulated:

1. Activated Carbon Beds (4'-diameter by 21-1/2'-high, dished heads, and 350 psig design pressure). The activated carbon beds are in vessels contained in a single vault . The vault is normally not accessible during operation because of the activity level; therefore, no failure due to an operator accident is considered.

   The only credible failure to these vessels that could result in loss of carbon from the vessels would be failure of the concrete structure surrounding the vessel. A circumferential failure could result from concrete falling on the vessel under one of two conditions:

   a. Bending Load - The vessel being supported in the center and loaded on each end. This could possibly result in a tear around 50 percent of the circumference.

   b. Shearing Load - The vessel being supported and loaded near the same point from above.

      In either case, no more than 10 to 15 percent of the carbon would be displaced from the vessel. Iodine is strongly bound to the activated carbon and would not be expected to be removed by exposure to the air. One percent of iodine is a conservative estimate. Moisture leakage from automatic closure valves would also affect the carbon bed performance but this has been considered in Table 9.5-4 and found to be negligible.

      Measurements made at KRB indicate that offgas is about 30 percent richer in krypton than air. Therefore, if this carbon is exposed to air, it will eventually attain equilibrium with the noble gases in the air. However, the first few inches of carbon will blanket the underlying carbon from the air. A 10 percent loss of noble gas from a failed vessel is conservative because of the small fraction of carbon exposed to the air.

2. Prefilter (24-inch diameter by 4-feet high, and 350 psig design pressure). Because of the short length of the vessel, heavy wall thickness due to the

design pressure, and collapsible nature of the filter media, a failure mechanism cannot be postulated that will result in emission of filter media or daughter products from this vessel.

One percent release is used to illustrate the consequences of loss from this vessel.

3. Holdup pipe. Pipe rupture and depressurization of the pipe is considered. The pipe will normally operate at less than 16.4 psia and depressurize to 14.4 psia. The possible loss is conservatively taken as 20 percent. The model used assumed plate-out or washout of 60 percent in calculating the holdup pipe inventory.

   To provide an estimate of hypothetical radiological doses from equipment failures, assumptions of percentages of the activity contained in the most significant components listed in Table 9.5-5 were assumed to be released to the environment under very stable 1 m/sec meteorological conditions with an effective release height of zero meters. The estimated percentages of activity released, and the resultant estimated radiological exposures based on the above considerations, are presented in Table 9.5-6. In addition, total failure of the nonseismically qualified portions of the system has been assumed and the total site boundary dose calculated. This total dose is included in Table 9.5-6.

4. Activated Carbon Temperature. The activated carbon adsorbers are designed to limit the temperature of the activated carbon to well below its ignition temperature, thus precluding overheating or fire and consequent escape of radioactive materials. The adsorbers are located in a shielded room, maintained at a constant temperature by an air-conditioning system that removes the decay heat generated in the adsorbers. The maximum centerline temperature of the activated carbon is less than 10°F above room temperature when gas flow is stopped. Failure of the air-conditioning system will cause an alarm in the control room. In any event, the decay heat of 50 Btu/hour is insignificant compared to the thermal mass of the activated carbon vault.

Additions of hydrogen recombiners, downstream of the air ejectors and upstream of the holding pipes, along with charcoal adsorption beds downstream of the holding pipes and upstream of the stack, have led to a lower maximum release limit of 3×10^{-2} Ci/sec annually for three units.

The activated carbon vault is controlled at about 77°F during operation of the plant. Failure of the air-conditioning system is alarmed and a redundant chiller is available. During a plant outage when the condenser is not maintained at vacuum, there is no gas flow in the activated carbon and holdup is very high, even if the activated carbon heats up to ambient temperature.

9.5.6 Inspection and Testing

The gaseous waste disposal systems are used on a routine basis and do not require specific testing to assure operability. Calibration and maintenance of monitoring equipment are done on a specific schedule and on indication of malfunction.

The particulate filters are tested after installation using a dioctylpthalate (DOP) test or equivalent. During operation, they are periodically tested by laboratory analyses of inlet and outlet Millipore filter samples.

Experience with boiling water reactors has shown that the response of the offgas and effluent monitors changes with isotopic content. Isotopic content can change depending on the presence or absence of fuel cladding leaks in the reactor and the nature of the leaks. Conservative setpoints will be calculated using χ_e - 133 efficiencies. The monitor responses are periodically compared to grab samples to provide timely information of changing plant parameters.