6.5 Fission Product Removal and Control Systems

Several U.S. EPR systems are designed to prevent or limit the release of fission products following a postulated design basis accident (DBA) or fuel handling accident. These systems include the engineered safety features (ESF) filter systems, the primary and secondary containment structures and systems, and the containment isolation system. This section describes the systems and how they mitigate fission product release. Section 15.0.3 presents the DBA radiological evaluations that demonstrate the effectiveness of these fission product removal and control systems in maintaining radioactivity releases within regulatory limits. The sequence of events assumed in the dose analyses for DBAs are also presented in Section 15.0.3.

6.5.1 ESF Filter Systems

ESF filter systems consist of filters, heaters, fans, dampers, and ductwork that remove particulate and gaseous radioactive material from the atmosphere. Four ESF filter systems work in conjunction with the five ventilation systems listed below:

- Main control room (MCR) air conditioning system (CRACS), described in Sections 6.4 and 9.4.1.
- Annulus ventilation system (AVS), described in Section 6.2.3.
- Safeguard building (SB) controlled area ventilation system (SBVS), described in Section 9.4.5.
- Fuel building (FB) ventilation system (FBVS), described in Section 9.4.2.
- Containment building ventilation system (CBVS) for the low-flow purge exhaust subsystem, described in Section 9.4.7.

The sections identified for the ventilation systems provide the descriptions and piping and instrumentation diagrams of these ventilation systems, along with design bases and safety evaluations.

Ventilation systems are aligned to ESF filter systems to support plant operations and accident mitigation. ESF filters in the CBVS low-flow purge exhaust subsystem are aligned during purging operations. The FBVS aligns to the SBVS ESF filters in response to a containment isolation signal.

6.5.1.1 Design Bases

The ESF filter systems mitigate the consequences of postulated accidents by removing particulate and gaseous radioactive material from the atmosphere that could be released to the environment (GDC 41). The ESF filter systems are designed to permit periodic inspection and periodic pressure and functional testing (GDC 42, GDC 43).

The ESF filter systems remove radioactive material from the atmosphere to maintain the MCR in a safe condition under accident conditions, including loss of coolant accidents (LOCA), in accordance with GDC 19. These systems, although not credited in the radiological analyses, also provide protection during fuel handling in accordance with GDC 61.

Design bases for radiation monitoring are presented in Section 12.3.4 and Section 11.5.1.

The ESF filter systems are designed to meet the design and performance requirements of RG 1.52, Revision 3, ASME N509 (Reference 1), and ASME N510 (Reference 2).

6.5.1.2 System Design

6.5.1.2.1 General System Design

The ESF filter systems described in this section are designed to limit the release of fission products to the environment and to limit radiation dose to the personnel in the MCR. Regardless of the application, each ESF filter system consists of two independent trains. Each train has an activated charcoal carbon adsorber with motorized dampers, an electric heater, a prefilter, and inlet and outlet high efficiency particulate air (HEPA) filters. A booster fan and isolation dampers are included to provide the flow to the vent stack for the discharge of filtered air.

Table 3.2.2-1 provides the seismic and other design classifications for the components of the ESF filter systems.

6.5.1.2.2 Component Design

Filter Air Heaters

The iodine adsorption efficiency of the filters decreases at high humidity. Therefore, the radiological filter air heaters limit the relative humidity to a maximum of 70 percent so that the carbon adsorber can remove iodine from the exhaust air. The filter air heaters are located upstream of the iodine filtration units to prevent excessive moisture accumulation in the charcoal filter beds. The heaters meet the requirements of ASME AG-1 (Reference 3). The heater sizes are as follows:

- AVS: 6 kW nominal heater rating.
- SBVS: 11 kW nominal heater rating.
- CRACS: 15 kW nominal heater rating.
- CBVS: 14 kW nominal heater rating.

Prefilters

The prefilters are located upstream of the HEPA filters and increase the life of the HEPA filters by collecting the larger particles. The prefilters maintain a minimum rated efficiency of 55–65 percent, which prevents the HEPA filters from becoming overloaded during radiological release events. The prefilters meet the requirements of ASHRAE Standard 52 (Reference 4). The filters are equipped with local differential pressure measurement, which indicates the degree of particulate loading and the need for filter change.

Moisture Separator

The moisture separator is a combination of moisture separator and prefilter. The moisture separator must meet the requirements of RG 1.52 (Reference 10), ASME N509 (Reference 1), and ASME AG-1 (Reference 3). The moisture separator is located upstream of the filter air heater and the HEPA prefilter. The moisture separator shall be a design that has been qualified by testing in accordance with the procedures described in Reference 1. Moisture separators must be capable of removing at least 99 percent by weight of entrained moisture in an air stream containing approximately 1.5–2 lb of entrained water per 1000 cubic feet, per Reference 1. Fiberglass knitted media within the moisture separator removes airborne particulates, which prevents the HEPA filters from becoming overloaded during radiological release events. The filters are equipped with local differential pressure measurement, which indicates the degree of particulate loading and the need for filter change.

HEPA Filters

HEPA filters are located upstream of the carbon adsorbers to prevent contamination of the carbon adsorbers. A single HEPA filter standard size is rated for 1,500 cfm of air flow and has a dust loading capacity of 1,140 grams. The HEPA filter has an initial pressure drop of 1.3 inches of water gauge and approximately 3 inches of water gauge with a full dust loading. The maximum mass loading of the HEPA filters resulting from a design basis accident is as follows:

- Annulus exhaust filtration system (AVS): 822 mg.
- Safeguard Building exhaust filtration system (SBVS): 631 mg.
- Main Control Room emergency filtration system (CRACS): 0.007 mg.

The filters are equipped with local differential pressure measurements that indicate the degree of load and the need for a filter change. HEPA filters are designed, constructed, qualified, and factory tested in accordance with ASME AG-1 (Reference 3). Each HEPA filter cell is manufacturer tested to achieve an efficiency of at least 99.97 percent and, once installed, is tested periodically according to ASME N510 (Reference 2) to confirm an efficiency of at least 99.95 percent.

Carbon Adsorbers

The radiological filters use activated charcoal with no more than 5 percent of impregnant to adsorb airborne radioiodine from the air. Carbon filters are designed to meet the requirements of RG 1.52 and the design of the carbon adsorber shall be ≤ 2.5 mg of total iodine per gram of charcoal. The maximum charcoal loading for the carbon adsorbent trains is as follows:

- Annulus exhaust filtration system (AVS): 0.08 mg/g
- Safeguard Building exhaust filtration system (SBVS): 0.94 mg/g
- Main Control Room emergency filtration system (CRACS): 2.0E-06 mg/g.

Each ESF carbon adsorber contains a four-inch-deep carbon bed with an average atmospheric residence time of 0.25 seconds per two inches of adsorber bed thickness and a laboratory decontamination efficiency of ≥ 99 percent, as tested per ASTM D3803 (Reference 5). Downstream of the carbon adsorbers, a HEPA filter removes entrained charcoal. Charcoal trays and screens are fabricated using all-welded construction to preclude potential loss of charcoal. The carbon adsorbers are equipped with differential pressure measurement to indicate the need for filter replacement. Carbon adsorbers are constructed, qualified, and tested in accordance with ASME AG-1 (Reference 3).

The maximum component temperature in the carbon adsorber section with normal air flow through the unit is 122°F. The maximum component temperature in the carbon adsorber section with the fan shut down and the carbon adsorption unit isolated post-LOCA is 148°F. The ignition temperature of the carbon adsorber is 625°F. The recommended limitation of the filter operating temperature is 250°F, per Nuclear Air Cleaning Handbook (Reference 11). A comparison of the recommended limitation of the filter operating temperature with the lower temperature of the isolated post-LOCA carbon adsorption unit, demonstrates that isolation provides an acceptable means of fire protection.

Fans

The fans used in the ventilation systems are exhaust fans. The fans are electric motor driven and are radial, axial, or centrifugal type, according to the system flow and pressure requirements. Fan operating characteristics, including flow rate and static head, are measured to confirm the required air delivery flow rates. Fan performance is rated in accordance with the applicable requirements of ANSI/AMCA-210 (Reference 6) or ANSI/AMCA-211 (Reference 7).

Dampers

The ESF filter systems use a variety of dampers, and the dampers have the same leakage rate criteria as the ducts on which they are installed. The backdraft dampers close to prevent potentially contaminated exhaust air from blowing back into the non-operating exhaust unit of the filter train.

The performance and testing requirements of the dampers are in accordance with the requirements of ANSI/AMCA-211 (Reference 7) and ANSI/AMCA-500 (Reference 8). Fire dampers are installed where ductwork penetrates a fire barrier; these dampers are designed and installed to the requirements of UL-555 (Reference 9).

6.5.1.3 Design Evaluation

The ESF filter systems are sized to remove fission products that may be released following postulated accidents so that offsite and control room doses remain within regulatory limits. Radiological analyses, source terms, methods, and assumptions for evaluating the radiological consequences of DBAs are described in Section 15.0.3.

The ESF filter systems have two redundant trains with suitable interconnections, leak detection, isolation, and containment capabilities. The ESF filter train is powered from an emergency bus that is backed up by an emergency diesel generator. Each ESF train is powered from a separate electrical division to maintain its safety function, assuming a single failure. The electrical divisions are addressed in Section 8.3.

The ESF filter systems permit periodic inspections and routine testing to confirm that the equipment is functional and can mitigate the consequences of postulated accidents. The ESF filter systems permit appropriate periodic inspection of components such as filters and ducts to verify the integrity and capability of the systems. The systems may be periodically operated to demonstrate that their components perform their required functions. The systems are monitored by instrumentation so that system operability and accident mitigation performance can be confirmed.

The ESF filter systems capacities are as follows:

- AVS: ≥ 1060 cfm and ≤ 1295 cfm (nominal 1177 cfm), face velocity 300 fpm, configuration 1 High x 1 Wide.
- SBVS: ≥ 2160 cfm and ≤ 2640 cfm (nominal 2400 cfm), face velocity 375 fpm, configuration 2 High x 1 Wide.
- CRACS: ≥ 3600 cfm and ≤ 4400 cfm (nominal 4000 cfm), face velocity 250 fpm, configuration 2 High x 2 Wide.
- CBVS: ≥ 2700 cfm and ≤ 3300 cfm (nominal 3000 cfm), face velocity 375 fpm, configuration 2 High x 1 Wide.

The ESF filter systems in the CRACS, AVS, and SBVS are aligned automatically with their associated ventilation systems upon receipt of an ESF actuation signal, including safety injection, or detection of high radiation levels (refer to Table 11.5-1, Monitors R-29 and R-30 (CRACs) and R-25 (SBVS)). The ESF filter systems may also be manually aligned. The ESF filter systems can also be aligned to the FB and the containment area during fuel handling of irradiated fuel assemblies. The systems are placed in line with the FBVS and CBVS in case of a fuel handling accident. With this ESF filter system alignment, the offsite release of radioactive material from a fuel handling accident does not exceed regulatory limits. During containment purging, the ESF filters in the low-flow purge exhaust subsystem of the CBVS are aligned to reduce radioactive releases in case of a rod ejection accident occurring during purging operations.

Each ESF filter system is sized to accommodate the required ventilation flow and to remove greater than 99 percent of the fission products that could be entrained in the air. The ESF filter systems conform to the requirements of RG 1.52.

Performance evaluations of the ventilation systems that operate in conjunction with the ESF filter systems to limit fission product release to the environment or the MCR are presented in the sections corresponding to the ventilation systems.

6.5.1.4 Tests and Inspections

Refer to Section 14.2 (test abstracts #076, #077, #082, and #083) for initial plant testing of the ESF filter systems. Routine testing and inspection of ESF filter systems are conducted under the ventilation filter testing program in Technical Specifications Section 5.5.10. Laboratory testing of samples of activated carbon adsorber material is performed in accordance with ASTM D3803 (Reference 5) and RG 1.52.

6.5.1.5 Instrumentation Requirements

Instrumentation and controls provide automatic operation and remote control of the ESF filter systems and continuous indication of system parameters.

6.5.1.6 Materials

The materials used for ESF filter systems are chosen considering environmental conditions, are consistent with acceptable construction practices, and meet the requirements of RG 1.52 and ASME AG-1 (Reference 3).

6.5.2 Containment Spray Systems

An automatically actuated containment spray system is not required to mitigate the consequences of a DBA, as presented in Section 6.2.1 and Section 15.0.3. However, a manually initiated containment spray system is provided for severe accident mitigation. This system is part of the severe accident heat removal system (SAHRS), which contains a containment dome spray system to reduce pressure and to remove fission products from the containment atmosphere under severe accident conditions. The SAHRS is described in Section 19.2.3.3. This system is not credited in the design basis containment or radiological analyses.

6.5.3 Fission Product Control Systems

The primary mechanism to limit release of fission products that are produced following a DBA is the Containment Building. The primary containment structure is a cylindrical building constructed from reinforced, post-tensioned concrete with a 0.25-inch thick steel liner. The Containment Building is protected from external hazards by the Shield Building. A detailed description of the entire RB is provided in Section 3.8.1.

Additional structures and systems that limit the release of fission products following a DBA are presented in this section.

6.5.3.1 Primary Containment

The primary containment requirements and performance for removal and control of fission products are described in the sections that detail the building structure, accident mitigation capabilities, allowable leakage limits, isolation capability, and the use of other systems that limit the spread of contamination and radiation. Table 6.5-1—Primary Containment Operations Following a Design Basis Accident summarizes primary containment provisions to control fission product releases following a DBA.

The RB structural design basis is specified and layout drawings are provided in Section 3.8.1. The containment design basis for accident mitigation is detailed in Section 6.2.1, which presents the sequence of events that occur within the Containment Building for each of the DBAs. The containment allowable leakage is defined and limits are stated in Section 6.2.6 and Section 5.5.15 of the Technical Specifications. The containment isolation system is described in Section 6.2.4. The control of hydrogen in containment during DBAs and severe accident conditions is described in Section 6.2.5. The ESF filter systems are described in Section 6.5.1. Natural deposition of radioactive particulates and elemental iodine on surfaces within containment is addressed in Section 15.0.3.11.

Periodic containment purging is possible during power operation using the low-flow purge exhaust subsystem of the CBVS. During purging operations, the ventilation system is aligned to ESF filters to filter radioactive releases in case of a rod ejection accident. Upon receipt of a containment isolation signal, the containment purge line is isolated within five seconds after receiving a signal from the PACS module.

Baskets of trisodium phosphate dodecahydrate (TSP-C) are stored in containment above the in-containment refueling water storage tank (IRWST). The TSP-C is positioned so that it is dissolved into the liquid inventory as the water drains back to the IRWST during a LOCA. The TSP-C baskets are further addressed in Section 6.3.2.2 and the description of the postaccident RB water chemistry control is addressed in Section 15.0.3.12.

Following a large-break LOCA, the safety injection system (SIS) draws borated water from IRWST and feeds to the reactor coolant system (RCS). Water from the SIS accumulators is also added during this phase. The combined inventory from the RCS and SIS contain a boric acid solution that lowers the pH. The addition of the TSP-C to the liquid inventory brings the pH of the total water mass to a value above 7.0. The desired pH level limits iodine re-evolution, corrosion, and the associated production of hydrogen.

The non-safety-related SAHRS, described in Section 19.2, provides defense-in-depth by scrubbing fission products from the primary containment atmosphere. This function is not needed to meet offsite and control room dose requirements for DBAs.

6.5.3.2 Secondary Containment

The Containment Building is surrounded by the reinforced concrete Shield Building; an annulus exists between the two structures. The SB and FB physically cover a portion of the Shield Building, including the areas containing the containment penetrations. The SB is divided into four areas, which each contain a train of safety systems or subsystems. SB 2 and SB 3 are concrete reinforced and contain the MCR. Near the SB, the Nuclear Auxiliary Building provides the location and facilities to process liquids and gases that come from, or are provided to, the RCS and other systems located inside containment. The Shield Building, the SB, and the FB structures are described in Section 3.8.4.

The AVS, described in Section 6.2.3, meets the requirements for a secondary containment system. Ventilation systems in the annulus, the SB, and the FB provide adequate ventilation to their assigned areas. These systems limit offsite and MCR doses from fission product releases to within the criteria of 10 CFR 52.47(a)(2)(iv) and GDC 19, respectively, through the use of the ESF filter systems.

Following a DBA, the AVS controls and removes fission products that leak from the primary containment. The AVS maintains the annulus at a slightly negative pressure to prevent leakage from the annulus through the Shield Building. A containment isolation actuation signal automatically aligns the discharge of the AVS through its ESF filter trains.

The SBVS services the SB and FB, including areas containing containment penetration piping. Pipes that penetrate the RB have the potential to create a bypass path for radioactive fission products through the annulus. Leakage from the safety injection pumps may also release radioactive fission products. The SB and FB capture bypass leakage from the RB and process it through SBVS, described in Section 9.4.5. ESF signals automatically align the discharge of SBVS through its ESF filter trains.

6.5.4 References

1. ANSI/ASME N509, “Nuclear Power Plant Air-Cleaning Units and Components,” American National Standards Institute/The American Society of Mechanical Engineers, 1989.

2. ANSI/ASME N510, “Testing of Nuclear Air Treatment Systems,” American National Standards Institute/The American Society of Mechanical Engineers, 1989.

3. ASME AG-1, “Code on Nuclear Air and Gas Treatment,” The American Society of Mechanical Engineers, 1997 (including the AG-1a-2000, “Housings” Addenda).

4. ASHRAE Standard 52, “Method of Testing General Ventilation Air-Cleaning Devices for Removal Efficiency by Particle Size (ANSI approved),” American Society of Heating, Refrigerating and Air Conditioning Engineers, 1999.

5. ASTM D3803, “Standard Test Method for Nuclear-Grade Activated Carbon,” American Society for Testing and Materials, 1989.

6. ANSI/AMCA-210, “Laboratory Methods for Testing Fans for Rating,” American National Standards Institute/American Movement and Control Association, 1999,

7. ANSI/AMCA-211, “Certified Ratings Program Air Performance,” American National Standards Institute/American Movement and Control Association, 1987.

8. ANSI/AMCA-500, “Test Methods for Louvers, Dampers, and Shutters,” American National Standards Institute/American Movement and Control Association, 1989.

9. UL-555, “Fire Dampers and Ceiling Dampers,” Underwriters Laboratories Inc., 1999.

10. Regulatory Guide 1.52, Revision 3, “Design, Inspection, and Testing Criteria for Air Filtration and Adsorption Units of Post-Accident Engineered-Safety-Feature Atmosphere Cleanup Systems in Light-Water-Cooled Nuclear Power Plants,” U.S. Nuclear Regulatory Commission, June 2001.

11. ERDA 76-21, “Nuclear Air Cleaning Handbook,” Oak Ridge National Laboratory, 1976.

Table 6.5-1—Primary Containment Operations Following a Design Basis Accident

Design	Description or Value
Type of structure	Concrete with steel liner
Free volume of primary containment	Approximately 2.8 x 10^6 ft^3
Internal fission product removal and control	Natural deposition, TSP-C for containment water pH buffering
Effectiveness of fission product removal systems	99%
Containment leakage rate	L_a (0.25% per day)
Containment isolation times	See Section 6.2.4
Secondary containment system	AVS (Section 6.2.3)
Purge and vent operation	Low-flow purge filtered through ESF filters. Containment isolation of purge line within 5 seconds on containment isolation signal.
Mode of hydrogen purge	None
Hydrogen recombination	No recombination assumed in design basis analysis (conservative). 47 PARs in containment.