Related Commercial Resources

# CHAPTER 29. NUCLEAR FACILITIES

THE HVAC requirements for facilities using radioactive materials are discussed in this chapter. Such facilities include nuclear power plants, fuel fabrication and processing plants, plutonium processing plants, hospitals, corporate and academic research facilities, and other facilities housing nuclear operations or materials. The information presented here should serve as a guide; however, careful and individual analysis of each facility is required for proper application.

## 1. GENERAL DESIGN ISSUES

Criticality, radiation fields, and regulation are three issues that are more important in the design of nuclear-related HVAC systems than in that of other special HVAC systems.

**Criticality.** Criticality considerations are unique to nuclear facilities. Criticality is the condition reached when the chain reaction of fissionable material, which produces extreme radiation and heat, becomes self-sustaining. Unexpected or uncontrolled conditions of criticality must be prevented at all cost. In the United States, only a limited number of facilities, including fuel-processing facilities, weapons facilities, naval shipboard reactors, and some national laboratories, handle special nuclear material subject to criticality concerns.

**Radiation Fields.** All facilities using nuclear materials contain radiation fields. They pose problems of material degradation and personnel exposure. Although material degradation is usually addressed by regulation, it must be considered in all designs. The personnel exposure hazard is more difficult to measure than the amount of material degradation because a radiation field cannot be detected without special instruments. It is the responsibility of the designer and of the end user to monitor radiation fields and limit personnel exposure.

**Regulation.** In the United States, the Department of Energy (DOE) regulates weapons-related facilities and national laboratories, and the Nuclear Regulatory Commission (NRC) regulates commercial nuclear plants. Other local, state, and federal regulations may also be applicable. For example, meeting an NRC requirement does not relieve the designer or operator of the responsibility of meeting Occupational Safety and Health Administration (OSHA) requirements. The design of an HVAC system to be used near radioactive materials must follow all guidelines set by these agencies and by the local, state, and federal governments.

For facilities outside the United States, a combination of national, local, and possibly some U.S. regulations apply. In Canada, the Canadian National Safety Commission (CNSC), formerly the Atomic Energy Control Board (AECB), is responsible for nuclear regulation, whereas in the United Kingdom, the Nuclear Installations Inspectorate (NII) and the Environment Agency (EA), are involved in issuing operation licenses.

## 1.1 AS LOW AS REASONABLY ACHIEVABLE (ALARA)

ALARA means that all aspects of a nuclear facility are designed to limit worker exposure and discharges to the environment to the minimum amount of radiation that is reasonably achievable. This refers not to simply meeting legal requirements, but rather to attaining the lowest cost-effective levels within those requirements.

## 1.2 DESIGN

HVAC requirements for a facility using or associated with radioactive materials depend on the type of facility and the specific service required. The following are design considerations:

- Physical layout of the HVAC system that minimizes the accumulation of material within piping and ductwork
- Control of the system so that portions can be safely shut down for maintenance and testing or in the case of any event, accident, or natural catastrophe that causes radioactivity to be released
- Modular design for facilities that change operations regularly
- Preservation of confinement integrity to limit the spread of radioactive contamination in the physical plant and surrounding areas

The design basis in existing nuclear facilities requires that safety-class systems and their components have active control for safe shutdown of the reactor, for mitigating a design basis accident (DBA) and for controlling radiation release to the environment as the result of an accident.

Advanced nuclear steam supply systems (NSSS) are being designed that incorporate more passive control to minimize dependence on mechanical equipment to mitigate the consequences of a DBA.

## 1.3 NORMAL OR POWER DESIGN BASIS

The normal or power design basis for nuclear power plants covers normal plant operation, including normal operation mode and normal shutdown mode. This design basis imposes no requirements more stringent than those specified for standard indoor conditions.

## 1.4 SAFETY DESIGN BASIS

The safety design basis establishes special requirements necessary for a safe work environment and public protection from exposure to radiation. Any system designated essential or safety related must mitigate the effect of a design basis accident, or natural catastrophe that may result in the release of radioactivity into the surroundings or the plant atmosphere. These safety systems must be operable at all times unless allowed by a limited condition of operation (LCO). The degree to which an HVAC system contributes to safety determines which components must function during and after a DBA or specific combinations of such events as a safe shutdown earthquake (SSE), a tornado, a loss of coolant accident (LOCA), fuel-handling accident (FHA), control rod drop accident (CRDA), main steam line break (MSLB), and loss of off-site electrical power (LOSP). Non-safety-related systems are not credited in any design basis accident and are designed not to adversely affect safety-related systems.

Most U.S. nuclear facilities (both NRC and DOE regulated) were built and licensed under the deterministic approach for safety classification of structures, systems, and components (SSC). This approach is changing to a probabilistic risk assessment (PRA) classification system. NRC classifies SSCs as safety-significant (SS) or low safety-significant (LSS), and categorizes them in four groups per 10 CFR 50.69 (RISC-1, safety related and safety significant; RISC-2, non-safety-related and safety significant; RISC-3, safety related and low safety significant; RISC-4, non-safety-related and low safety significant). NRC *Regulatory Guide* 1.201 provides information on safety classification of systems, structures, and components. The U.S. DOE classifies SSCs based on DOE *Order* 420.1 and DOE *Standards* 1020 and 1189.

**System Redundancy.** Systems important to safety must be redundant and single-failure-proofed. Such a failure should not cause a failure in the back-up system. For additional redundancy requirements, refer to the section on Commercial Facilities.

**Seismic Qualification.** All safety-class components, including equipment, pipe, duct, and conduit, must be seismically qualified by testing or calculation to withstand and perform under the shock and vibration caused by an SSE or an operating-basis earthquake (OBE) (the largest earthquake postulated for the region). This qualification also covers any amplification by the building structure. In addition, any HVAC component that could, if it failed, jeopardize the essential function of a safety-related component, must be seismically qualified or restrained to prevent such failure.

**Environmental Qualification.** Safety-class components must be environmentally qualified; that is, the useful life of the component in the environment in which it operates must be determined through a program of accelerated aging. Environmental factors such as temperature, humidity, pressure, and cumulative radiation dose must be considered.

**Quality Assurance.** All designs and components of safety-class systems must comply with the requirements of a quality assurance (QA) program for design control, inspection, documentation, and traceability of material. For U.S. plant designs, refer to Appendix B of Title 10 of the U.S. *Code of Federal Regulations*, Part 50 (10 CFR 50) or ASME *Standard* NQA-1 for quality assurance program requirements.

Canadian plant designs use two related series of quality assurance standards: CAN3-286.0 and its six daughter standards, plus four standards in the N299 series. Quality programs in the United Kingdom are based on ISO 9000. For other countries, refer to the applicable national regulations.

**Emergency Power.** All safety-class systems must have a backup power source such as an emergency diesel generator.

## 1.5 OUTDOOR CONDITIONS

Chapters 14 and 15 of the 2021 *ASHRAE Handbook—Fundamentals*, the U.S. National Oceanic and Atmospheric Administration, national weather service of the site country, or site meteorology can provide information on outdoor conditions, temperature, humidity, solar load, altitude, and wind.

Nuclear facilities generally consist of heavy structures with high thermal inertia. Time and temperature lag should be considered in determining heat loads. For some applications, such as diesel generator buildings or safety-related pumphouses in nuclear power plants, the 24 h average temperature may be used as a steady-state value. For critical ventilation system design, site meteorological data should be evaluated.

## 1.6 INDOOR CONDITIONS

Indoor temperatures are dictated by occupancy, equipment or process requirements, and comfort requirements based on personnel activities. HVAC system temperatures are dictated by the environmental qualification of the safety-class equipment located in the space and by ambient conditions during the different operating modes of the equipment.

## 1.7 INDOOR PRESSURES

Where control of airflow pattern is required, a specific building or area pressure relative to the outdoor atmosphere or to adjacent areas must be maintained. The effect of prevailing wind speed and direction, based on site meteorological information, should be considered. For process facilities with pressure zones, the pressure relationships are specified in the section on Confinement Systems.

In facilities where zoning is different from that in process facilities, and in cases where any airborne radioactivity must not spread to rooms within the same zone, this airborne radioactivity must be controlled by airflow.

## 1.8 AIRBORNE RADIOACTIVITY

The level of airborne radioactivity within a facility and the amount released to the surroundings must be controlled to meet the requirements of 10 CFR 20, 10 CFR 50, 10 CFR 61, 10 CFR 100, 10 CFR 835, and U.S. DOE *Policy* P 450.4A, or equivalent national regulations of the site country.

## 1.9 TORNADO/MISSILE PROTECTION

Protection of buildings, housings, and essential equipment from effects of tornados and missiles launched by wind or other design basis events is required to allow controlled shutdown of the plant. A tornado passing over a facility causes a sharp drop in ambient pressure. If exposed to this transient pressure, ducts and filter housings could collapse because the pressure inside the structure would still be that of the environment prior to the pressure drop. Protection is usually provided by tornado dampers and missile barriers in all appropriate openings to the outdoors. Tornado dampers are heavy-duty, low-leakage dampers designed for pressure differences in excess of 20 kPa. They are normally considered safety-class and are environmentally and seismically qualified.

## 1.10 FIRE PROTECTION

Fire protection for HVAC and filtration systems must comply with applicable requirements of RG 1.189, Appendix R of 10 CFR 50, and NFPA, UL, and ANSI or equivalent standards of the site country. Design criteria should be developed for all building fire protection systems, including secondary sources, filter plenum protection, fire dampers, and systems for detection/suppression and smoke management. Fire protection systems may consist of a combination of building sprays, hoses and standpipes, and gaseous or foam suppression. The type of fire postulated in the Fire Hazard Analysis (FHA) or equivalent determines which kind of system is used.

A requirement specific to U.S. nuclear commercial facilities is protection of carbon filter plenums and ventilation ductwork. Manually activated water sprays (window nozzles, fog nozzles, or standard dry pipe/wet pipe system spray heads) are usually used for fire suppression in carbon filter plenums.

Heat detectors and fire suppression systems should be considered for special equipment such as glove boxes. Application of the two systems in combination allows the shutdown of one system at a time for repairs, modifications, or maintenance.

In a DOE facility, the exhaust system duct penetrating a fire-rated boundary does not need a fire damper for maintaining the integrity of the boundary if the duct is fire rated. The exhaust duct may be rated at up to two hours by either wrapping, spraying, or enclosing the duct in an approved material and qualifying it by an engineering analysis. Additional design guidance can be obtained from the *Nuclear Air Cleaning Handbook* (DOE-HDBK-1169-2003) and *Fire Protection* (DOE-STD-1066-2016).

Fire protection and smoke control criteria can be found in NFPA *Standards* 801, 803, 804, 805, and 901, or equivalent standards of the site country.

## 1.11 SMOKE MANAGEMENT

The design objective for smoke management in a nuclear facility is to protect the plant operators and equipment from internally and externally generated smoke. Smoke management involves (1) use of materials with low smoke-producing characteristics, (2) prevention of smoke movement to areas where operators may be overcome, (3) use of differential pressures to contain smoke to fire areas, (4) smoke venting to permit access to selected areas, and (5) purging to permit access to areas after a fire.

Smoke control may be static, by prevention of smoke movement (NFPA 90A), or it may be dynamic, by controlling building pressure or air velocities (NFPA 92A). Ventilation systems in the affected areas should be shut down to prevent smoke from migrating and overcoming occupants in other areas. Smoke management for an *internal* fire source should allow the plant operator to shut down the reactor in a controlled manner and maintain shutdown condition. Smoke from an *external* fire should be isolated and appropriate measures provided to prevent smoke from entering the main control room envelope. This envelope includes the main control room and other necessary areas such as restrooms, kitchens, and offices. The location of the safe shutdown panels and the pathway to the safe shutdown panel must be such that, in case of abandonment of the main control room because of fire and smoke, safe egress is ensured.

Capabilities should be provided for purging smoke from fire areas to permit reentry into the areas after the fire is isolated and extinguished. Venting may be used to remove heat and smoke at the point of the fire to permit firefighting and to control pressures generated by fires.

NFPA 90A, 204, and 92A and NUREG 800 SRP Branch Technical Position CMEB 9.5.1.1 provide guidance for smoke management and discuss the discharge of smoke and corrosive gases.

## Control Room Habitability Zone

The HVAC system in a control room is a safety-related system that must fulfill the following requirements during all normal and postulated accident conditions:

- Maintain conditions comfortable to personnel, and ensure that control room equipment functions continuously and complies with its qualification limit
- Protect personnel from exposure to radiation or toxic chemicals, in the event of a design basis accident
- Protect personnel from combustion products (smoke) emitted from on-site and off-site fires
- Limit unfiltered in-leakage to that credited in the design basis dose calculation.

Additional information may be obtained from the NRC Standard Review Plans (NUREG 800), Sections 6.4 and 9.4.1, and TSTF *Standard* 448, Revs. 0 and 3.

## Air Filtration

HVAC filtration systems can be designed to remove either radioactive particles or radioactive gaseous iodine from the airstream. They filter potentially contaminated exhaust air prior to discharge to the environment and may also filter potentially contaminated makeup air for power plant control rooms and technical support centers.

The composition of the filter train is dictated by the type and concentration of the contaminant, the process air conditions, and the filtration levels required by the applicable regulations (e.g., NRC *Regulatory Guides* RG 1.52, RG 1.140; ASME AG-1, N509, and 510 [for equipment designed to N509], and N511 [for equipment designed to AG-1]; 10 CFR 20, 10 CFR 100). Filter trains may consist of one or more of the following components: prefilters, high-efficiency particulate air (HEPA) filters, carbon filters (adsorbers), heaters, demisters and associated ductwork, housings, fans, dampers, and instrumentation. For nuclear-safety-related versions of this equipment, the latest edition of ASME AG-1 codifies rules for materials; design; inspection and testing; fabrication; packaging, shipping, receiving, storage, and handling; and quality assurance. Information common to all equipment is compiled in AG-1, Section AA: General Requirements. The AG-1 code discusses specific rules for each of the major components in separate sections

For DOE facilities, the *Nuclear Air Cleaning Handbook* (DOE-HDBK-1169-2003) recommends the design of systems and use of major components for nuclear process facilities and laboratories.

**Demisters (Mist Eliminators).** Demisters are required to protect HEPA and carbon filters if entrained moisture droplets are expected in the airstream. They should be fire resistant. For details, see AG-1, Section FA.

**Heaters.** Electric heating coils may be used to limit the relative humidity to 70% for carbon filters based on credited laboratory test condition. For safety-class systems, electric heating coils should be connected to the emergency power supply. Interlocks should be provided to prevent heater operation when the exhaust fan is de-energized. For details, see AG-1, Section CA.

**Prefilters/Postfilters.** Extended-surface filters are selected for the efficiency required by the particular application. AG-1, Table FB-4200-1, lists the average atmospheric dust spot efficiency ranges. AHRI 850 provides efficiency tolerances for the various classes. These types of filters are often used as prefilters for HEPA filters to prevent them from being loaded with atmospheric dust and to minimize replacement costs. High-efficiency (90 to 95%) filters are also often used as postfilters downstream of the carbon filter in lieu of downstream HEPAs. For details, see AG-1, Section FB.

European filter standards use efficiency tolerances from ISO 16890 in place of ARI 850.

**HEPA Filters.** HEPA filters are used where there is a risk of particulate airborne radioactivity. For details, see AG-1, Sections FC and FK. For DOE sites, the construction and quality assurance testing of HEPA filters are per DOE *Standards* 3020 and 3025.

**Carbon Filters.** Activated carbon adsorbers are used mainly to remove radioactive iodine in gaseous state. Bed depths are typically 50 or 100 mm. Carbon filters have an efficiency 95 to 99% for organic iodine, although they lose efficiency as relative humidity increases. For this reason, they are often preceded by a heating element to keep the relative humidity of the entering air below 70%, and are tested at that condition. If the heater operation is not credited for maintaining relative humidity of the air stream, the carbon is tested at relative humidity of 95%. Nuclear carbon filters can be either tray type (Type II), rechargeable (Type III), or modular (Type IV). For details on each type, see AG-1, Sections FD, FE, and FH. Carbon efficiency is tested in accordance with Generic Letter 99-02 and ASTM D3803-89 (2014) or its latest edition.

Both carbon and HEPA filters may be affected by exposure to paint solvent, chemicals, and fire, and thus should be evaluated on exposure.

Design information for ventilation and air-conditioning system design, ductwork, housings, fans, dampers, and instrumentation are contained in AG-1, Sections CA, RA, SA, HA, BA, DA, and IA, respectively.

**Sand Filters.** Sand filtration is a passive air filtration system that consists of multiple layers of sand and gravel through which air is drawn and filtered. The air enters an inlet tunnel that runs the entire length of the filter. Smaller cross-sectional laterals running perpendicular to the inlet tunnel distribute air across the base of the sand. Air rises through several layers of various sizes of sand and gravel, typically at a facial velocity of 25 mm/s. It is then collected in the outlet tunnel for discharge to the atmosphere. Sand filters require no maintenance, and the sand is not changed or replaced during its active service life. A detailed discussion of sand filters is given in Chapter 9 of the DOE's (2003) *Nuclear Air Cleaning Handbook*. Additionally, AG-1, Section FL, issued by ASME's Code of Nuclear and Air Gas Treatment (CONAGT) Committee, addresses deep bed sand filters.

## 2. DEPARTMENT OF ENERGY FACILITIES

The following discussion applies to U.S. National Laboratory facilities. Nonreactor nuclear HVAC systems must be designed in accordance with DOE *Order* O 420.1 and the associated DOE standards, guides, and handbooks listed at the end of this chapter. Critical items and systems in plutonium processing facilities are designed to confine radioactive materials under both normal and DBA conditions.

## 2.1 CONFINEMENT SYSTEMS

### Zoning

Typical process facility confinement systems are shown in Figure 1. Process facilities comprise several zones.

**Primary Confinement Zone.** This zone includes the interior of the hot cell, canyon, glove box, or other means of containing radioactive material. Containment must prevent the spread of radioactivity within or from the building under both normal conditions and upset conditions up to and including a facility DBA. Complete isolation from neighboring facilities is necessary. Multistage HEPA filtration of the exhaust is required.

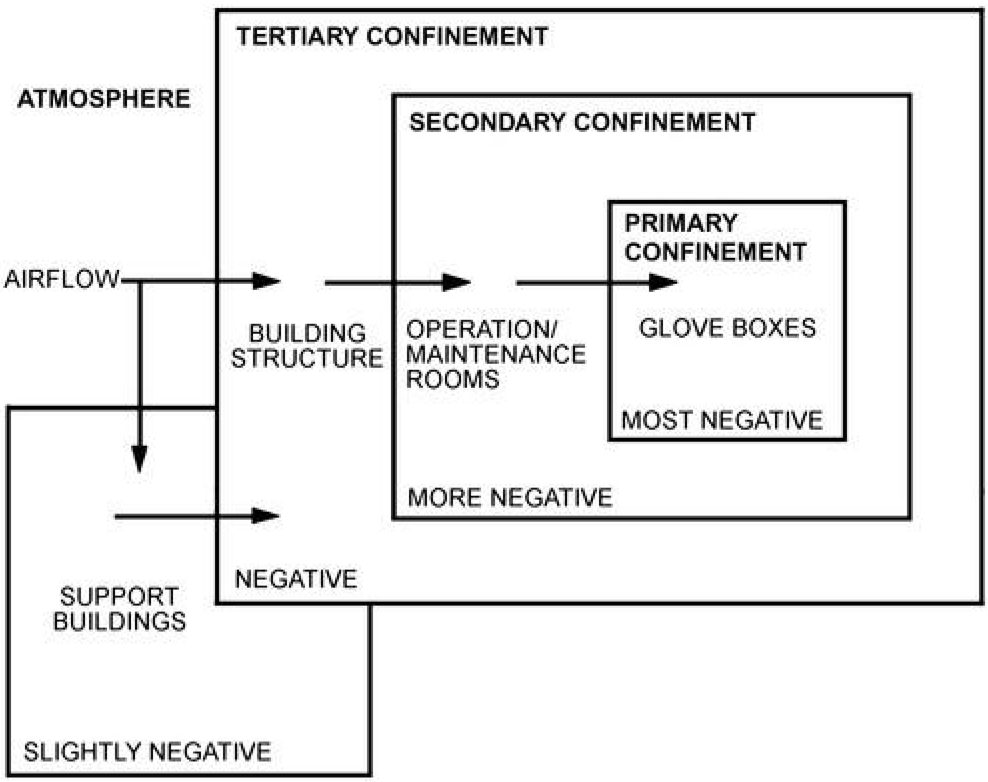

**Figure 1. Typical Process Facility Confinement Categories**

**Secondary Confinement Zone.** This zone is bounded by the walls, floors, roofs, and associated ventilation exhaust systems of the operating and maintenance areas or rooms surrounding the primary confinement zone.

**Tertiary Confinement Zone.** This zone is bounded by the walls, floors, roofs, and associated ventilation exhaust systems of the facility. They provide a final barrier against the release of hazardous material to the environment. Radiation monitoring may be required at exit points.

**Uncontaminated Zone.** This zone includes offices and cold shop areas.

### Air Locks

Air locks in nuclear facilities are used as safety devices to maintain a negative differential pressure when a confinement zone is accessed. They are used for placing items in primary confinement areas and for personnel entry into secondary and tertiary confinement areas. Administrative controls ensure proper operation of the air lock doors.

There are three methods of ventilating personnel air locks (ventilated vestibules):

- The **clean conditioned supply air** method, where the air lock is at positive pressure with respect to the adjacent zones. For this method to be effective, the air lock must remain uncontaminated at all times.
- The **flow-through ventilation air** method, where no conditioned air is supplied to the air lock and the air lock stays at negative pressure with respect to the less contaminated zone.
- The **combined ventilation air** method, which is a combination of the other two methods. This may be the most effective method, when properly designed.

### Zone Pressure Control

Negative static pressure increases (becomes more negative) from the uncontaminated zone to the primary confinement zone, causing any air leakage to be inward, toward areas of higher potential contamination. All zones should be maintained negative with respect to atmospheric pressure. Zone pressure control cannot be achieved through the ventilation system alone; confinement barrier construction must meet all applicable specifications.

### Cascade Ventilation

Confinement barriers are enhanced by the use of a cascaded ventilation system, in which pressure gradients cause air to flow from areas of lower contamination to areas of higher contamination through engineered routes. In a cascade ventilation system, air is routed through areas or zones from lower contamination to higher contamination and then to highest contamination, thus reducing the number of separate ventilation systems and the amount of air required for contamination control.

Properly designed air locks should be provided for access between noncontaminated and contaminated areas. If there is a potential for development of differential pressure reversal, HEPA filters should be used at the inlet air openings between areas of higher and lower contamination levels to control the spread of contamination into less contaminated or cleaner areas. Appropriate sealing mechanisms should be used for doors or hatches leading into highly contaminated areas.

### Differential Pressures

Differential pressures help ensure that air flows in the proper direction in case of a breach in a confinement zone barrier. The design engineer must incorporate the desired magnitudes of the differential pressures into the design early to avoid later operational problems. These magnitudes are normally specified in the design basis document of the safety analysis report (SAR). The following are approximate values for differential pressures between the three confinement zones.

**Primary Confinement.** With respect to the secondary confinement area, air-ventilated glove boxes are typically maintained at pressures of –75 to –312 Pa, inert gas glove boxes at –75 to –375 Pa, and canyons and cells at a minimum of –250 Pa.

**Secondary Confinement.** Differential pressures of –25 to –37 Pa with respect to the tertiary confinement area are typical.

**Tertiary Confinement**. Differential pressures of –2.5 to –37 Pa with respect to the atmosphere are typical.

## 2.2 VENTILATION

Ventilation systems are designed to confine radioactive materials under normal and DBA conditions and to limit radioactive discharges to allowable levels. They ensure that airflows are, under all normal conditions, toward areas (zones) of progressively higher potential radioactive contamination. Air-handling equipment should be sized conservatively so that upsets in the airflow balance do not cause the airflow to reverse direction. Examples of upsets include improper use of an air lock, a credible breach in the confinement barrier, or excessive loading of HEPA filters.

HEPA filters at the ventilation inlets in all primary confinement zone barriers prevent movement of contamination toward zones of lower potential contamination in case of an airflow reversal. Ventilation system balancing helps ensure that the building air pressure is always negative with respect to the outdoor atmosphere.

Recirculating refers to the reuse of air in a particular zone or area. Room air recirculated from a space or zone may be returned to the primary air-handling unit for reconditioning and then, with the approval of health personnel, be returned to the same space (zone) or to a zone of greater potential contamination. All air recirculated from secondary and tertiary zones must be HEPA-filtered before reintroduction to the same space. Recirculating air is not permitted in primary confinement areas, except those with inert atmospheres.

A safety analysis is necessary to establish minimum acceptable response requirements for the ventilation system and its components, instruments, and controls under normal, abnormal, and accident conditions.

Analysis determines the number of exhaust filtration stages required in different areas of the facility to limit (in conformance with the applicable standards, policies, and guidelines) the amount of radioactive or toxic material released to the environment during normal and accident conditions. Consult DOE *Order* O 420.1, *Standard* 1189, and Handbook 1169 (DOE 2003) for air-cleaning system criteria.

## Ventilation Requirements

A partial recirculating ventilation system may be considered for economic reasons. However, it must be designed to prevent contaminated exhaust from entering the room air-recirculating systems.

The exhaust system is designed to (1) clean radioactive contamination from the discharge air, (2) safely handle combustion products, and (3) maintain the building under negative pressure relative to the outdoors.

Provisions may be made for independent shutdown of ventilation systems or isolation of portions of the systems to facilitate operations, filter change, maintenance, or emergency procedures such as firefighting. All possible effects of partial shutdown on the airflows in interfacing ventilation systems should be considered. Positive means must be provided to control the backflow of air that might transport contamination. A HEPA filter installed at the interface between the enclosure and the ventilation system minimizes contamination in the ductwork; a prefilter reduces HEPA filter loading. These HEPA filters should not be considered the first stage of an airborne contamination cleaning system.

## Ventilation Systems

The following is a partial list of elements that may be included in the overall air filtration and air-conditioning system:

- Air-sampling devices
- Pre- and/or postfilters (e.g., carbon adsorbers, deep bed sand, HEPA)
- Scrubbers
- Demisters
- Process vessel vent systems
- Condensers
- Distribution baffles
- Fire suppression systems
- Fire and smoke dampers
- Exhaust stacks
- Fans
- Coils
- Heat removal systems
- Pressure- and flow-measuring devices
- Duct test ports

- Radiation-measuring devices
- Criticality-safe drain systems
- Tornado dampers
- Smoke dampers

The ventilation system and associated fire suppression system are designed for fail-safe operation. The ventilation system is equipped with alarms and instruments that report and record its behavior through readouts in control areas and utility service areas.

### Control Systems

Control systems for HVAC systems in nuclear facilities have some unique safety-related features. Because the exhaust system is to remain in operation during both normal and accident-related conditions, redundancy in the form of standby fans is often provided. These standby fans and their associated isolation dampers energize automatically upon a set reduction in either airflow rate or specific location pressure, as applicable. For DOE facilities, maintaining exhaust airflow is important, so fire dampers are excluded from all potentially contaminated exhaust ducts.

Pressure control in the facility interior maintains zones of increasing negative pressure in areas of increasing contamination potential. Care must be taken to prevent wind from unduly affecting the atmospheric control reference. Pulsations can cause the pressure control system to oscillate strongly, resulting in potential reversal of relative pressures. One alternative is to use a variety of balancing and barometric dampers to establish an air balance at the desired differential pressures, lock the dampers in place, and then control the exhaust air to a constant flow rate.

### Air and Gaseous Effluents Containing Radioactivity

Air and all other gaseous effluents are exhausted through a ventilation system designed to remove radioactive particulates. Exhaust ducts or stacks located downstream of final filtration that may contain radioactive contaminants should have two monitors, one a continuous air monitor (CAM) and the other a fixed sampler. These monitors may be a combination unit. Exhaust stacks from nuclear facilities are usually equipped with an isokinetic sampling system that relies on a relatively constant airflow rate. The isokinetic sensing probe is a symmetrically arranged series of pickup tubes connected through sweeping bends to a stainless steel header that connects with capillary tubing to a sampling station (CAM). The air velocity through an isokinetic sampling system should be the same as the airstream being sampled. This ensures that particles captured by the isokinetic sampling probe and conveyed to the sampling station are the same size particles that are conveyed in the airstream being sampled. Typically, an exhaust system flow controller modulates the exhaust fan inlet dampers or motor speed to hold the exhaust airflow rate steady while the HEPA filters load.

CAMs can also be located in specific ducts where a potential for radiological contamination has been detected. These CAMs are generally placed beyond the final stage of HEPA filtration, as specified in HPS *Standard* N13.1. Each monitoring system is connected to an emergency power supply.

The following are design considerations for CAM systems:

- Maintain fully developed turbulent flow at the nonisokinetic sampling point.
- Maintain fully developed laminar flow at the isokinetic sampling point.
- Ensure fully developed turbulent flow is established between the final filtration and the isokinetic sampling point.
- For accurate CAM operation, heat tracing on the sampling air tubing may be required.
- Maintain the ratio of the sample airflow rate to total discharge airflow rate constant.

# 3. COMMERCIAL FACILITIES

## 3.1 OPERATING NUCLEAR POWER PLANTS

The two kinds of commercial light-water power reactors currently in operation in the United States, and in many other countries, are the pressurized water reactor (PWR) and the boiling water reactor (BWR). Heavy water (deuterium oxide) reactors are used in Canada and some other countries. Gas-cooled reactors constitute most of the installed base in Great Britain, but are in the process of being phased out. For all these types, the main objective of the HVAC systems, in addition to ensuring personnel comfort and reliable equipment operation, is protecting operating personnel and the general public from airborne radioactive contamination during normal and accident conditions. Radiation exposure limits are controlled by 10 CFR 20. The "as low as reasonably achievable" (ALARA) concept is the design objective of the HVAC system. The radiological dose is not allowed to exceed the limits as defined in 10 CFR 50 and 10 CFR 100. For other countries operating commercial nuclear plants, the specific national rules and regulations should be consulted.

NRC Regulatory Guides (RGs) delineate techniques of evaluating specific problems and provide guidance to applicants concerning the information the NRC needs for its review of the facility. The regulatory guides that relate directly to HVAC system design are RG 1.52, RG 1.78, RG 1.140, RG 1.194, RG 1.196, and RG 1.197. Deviations from RG criteria must be justified by the owner and approved by the NRC. Some countries also invoke NRC regulatory guides as part of the design requirements. Deviations from RG criteria must be requested through the applicable government agency in the country of construction.

The design of the HVAC systems for a U.S. nuclear power generating station must ultimately be approved by the NRC in accordance with Appendix A of 10 CFR 50. The NRC developed standard review plans (SRPs) as part of Regulatory Report NUREG-0800 to provide an orderly and thorough review. The SRP provides a good basis or checklist for the preparation of a safety analysis report (SAR). The SRP is the basis for information provided by an applicant in an SAR as required by Section 50.34 of 10 CFR 50. Technical specifications for nuclear power plant systems are developed by the owner and approved by the NRC as outlined in Section 50.36 of 10 CFR 50. Technical specifications define the safety limits, limiting conditions for operation (LCO), and surveillance requirements (SR) for all systems important to plant safety.

Minimum requirements for the performance, design, construction, acceptance testing, and quality assurance of equipment used in safety-related air and gas treatment systems in nuclear facilities are found in ASME N509, N510, N511, and AG-1.

Temperature and humidity conditions are dictated by the nuclear steam supply system (NSSS). For U.S. plants, the common modes of operation are normal, hot shutdown, cold shutdown, and refueling.

**Normal Operation.** NSSS temperature and humidity requirements are specified by the NSSS supplier. Some plants require recirculation filtration trains in the containment building to control the level of airborne contamination. In existing plants, containment cooling is necessary for maintaining the components in the containment and to ensure that design limits are not exceeded during accidents. Cooling is provided by a containment cooling system. Some next-generation plants are mostly of passive design and thus do not need active containment cooling systems.

**Refueling Condition.** The temperature in the refueling or fuel-handling area is determined by the need to perform refueling activities safely. Also, because personnel work in protective clothing, they can be vulnerable to heat stress. To prevent this, area cooling can be provided by a normal non-safety-related cooling system. Outdoor air should be provided for ventilation.

## Accident Scenarios

Plants are analyzed for four types of accidents: (1) loss of coolant accident (LOCA), (2) fuel handling accident (FHA), (3) control rod drop accident (CRDA), and (4) a main steam line break (MSLB). For all plant types, it necessary to evaluate the limiting accident event and to conduct safety assessments, so measures can be taken to mitigate any accident's any accident's consequences.

## Major NSSS Types

**Pressurized-Water Reactors (PWRs).** These reactors, widely used in the United States, use enriched uranium for fuel. The reactor, steam generators, and other components of the NSSS are housed in the containment structure. Other support systems are housed in the auxiliary building, control building, turbine building, and diesel building. In PWR design, the steam turbine is powered by nonradioactive steam for the generation of electricity. General design requirements of the PWR plant are contained in ANSI/ANS *Standard* 56.6-1986. Figure 2 shows a typical PWR.

**Boiling-Water Reactor (BWRs).** Also widely used in the United States, this type of design reactor uses enriched uranium for fuel. The reactor pressure vessel and related piping are housed within the primary containment, which is also referred to as the drywell (Figure 3). The drywell is a low-leakage, pressure-retaining structure designed to withstand the high temperature and pressure from a major break in the reactor coolant line. The drywell is housed within a concrete structure called the secondary containment or the reactor building. Other support systems are housed in the control building, turbine building, and diesel building. In BWR design, the steam turbine is powered by radioactive steam for the generation of electricity. General design requirements of the BWR plant are contained in ANSI/ANS *Standard* 56.7-1987.

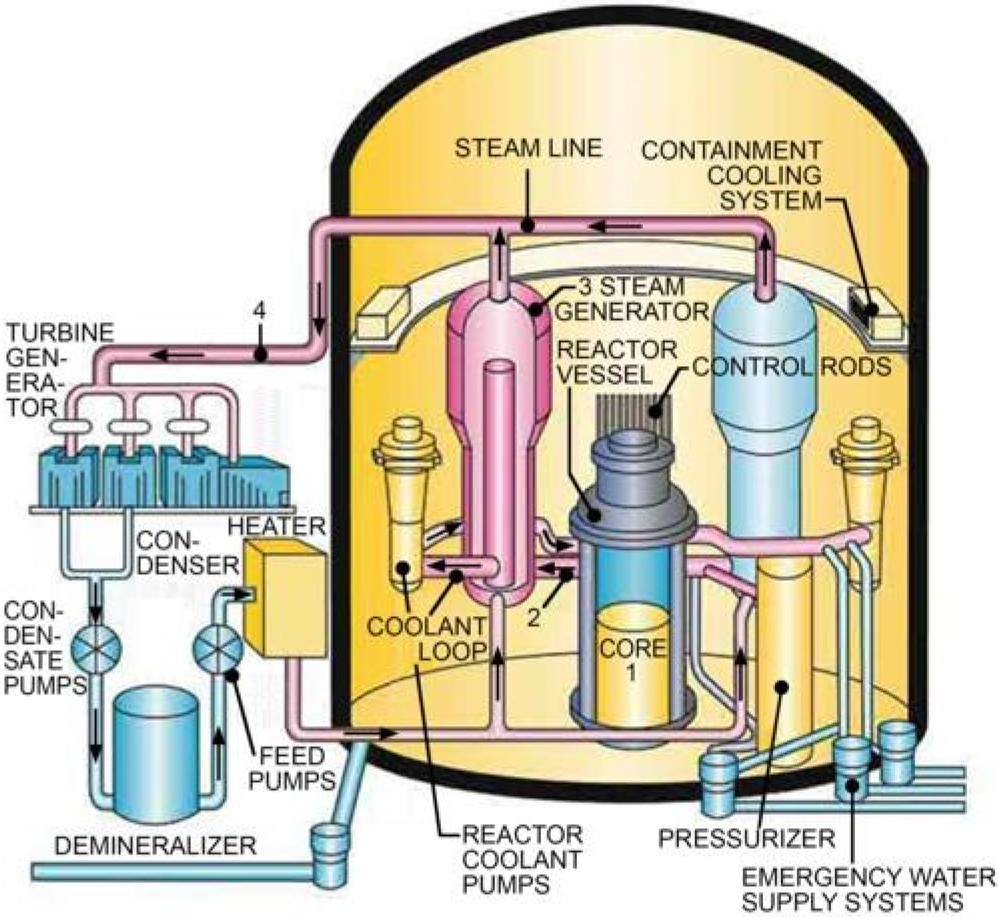


**Figure 2. Typical Pressurized-Water Reactor (From NRC web site: www.nrc.gov)**

**Heavy Water Reactors.** Canadian power reactors use natural uranium fuel and heavy water (deuterium oxide), which acts as a moderator and a coolant source. The reactor core is mounted in a large, horizontal steel vessel called a calandria, which is enclosed in a concrete containment structure. This design enables the reactors to be refueled while the unit is operating at full power.

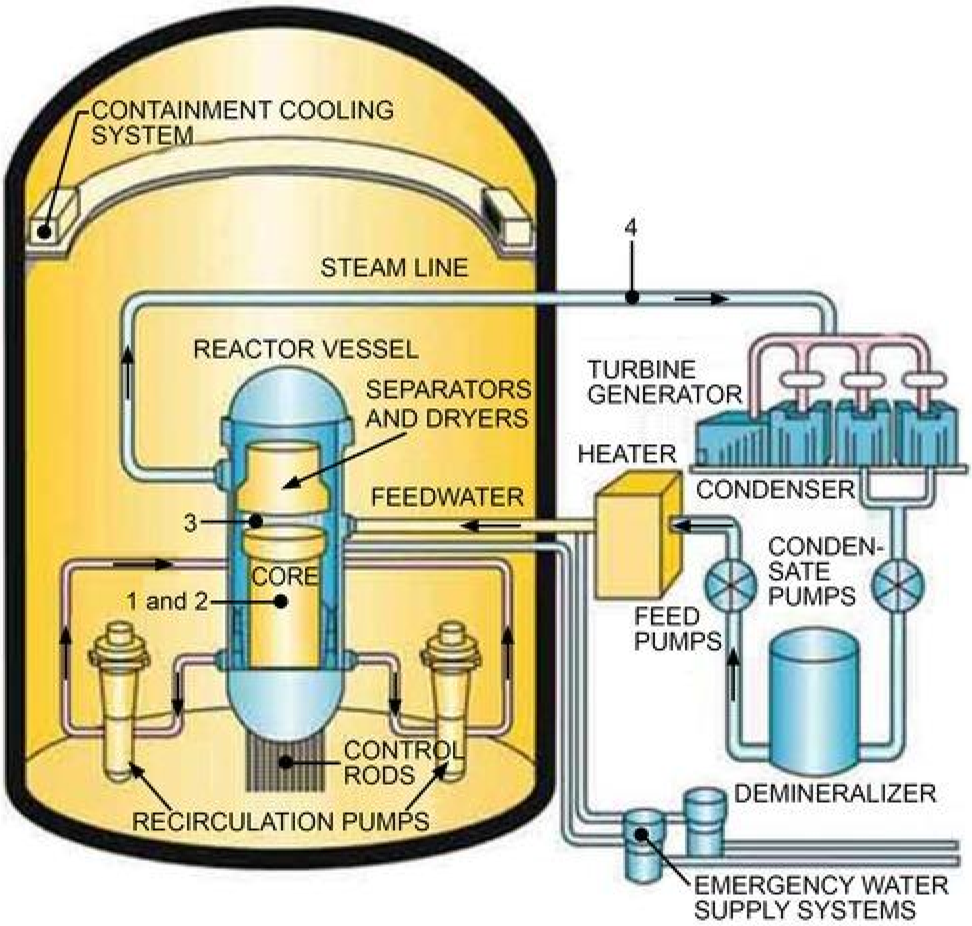


**Figure 3. Typical Boiling-Water Reactor (From NRC web site: www.nrc.gov)**

### Commercial Plant License Renewal and Power Uprate

Nuclear power plants were originally licensed for a 40 year term and a defined power output capacity. Most nuclear plants currently operating in the United States have applied for or will be applying for license renewal to extend the plant operating license from 40 to 60 years. As part of the license renewal process, passive plant components, such as HVAC ductwork and piping, are reviewed, and renewal licenses are granted based on the commitment to perform aging management review (AMR) of long-lived components. Credit is taken for the maintenance rule to address upkeep and replacement of active components. Maintenance rule requirements are outlined in 10 CFR 50.65, Nuclear Energy Institute documents, Nuclear Management Resources Council (NUMARC) 93-0, and NRC Regulatory Guide RG 1.160.

In addition to license renewal, most plants are increasing their power output capacity by as much as 5 to 15% by conducting power uprate evaluations. Power uprates are often done in steps, and are often categorized as (1) measurement uncertainty recapture power uprates, (2) stretch power uprates, and (3) extended-power uprates. As part of the power uprate, the effects of power output on plant and HVAC systems are evaluated, and these systems are upgraded as needed.

## 3.2 NEW NUCLEAR POWER PLANTS

Many new nuclear power generation plants are being considered for construction in the United States, as well as in other parts of the world. The U.S. NRC has streamlined the application and licensing process for the new reactors, and the *Code of Federal Regulations* 10 CFR 52 governs the issuance of combined construction and operating license. The new plants are being designed and licensed to satisfy the demand for additional generation capacity in a competitive environment, while contributing to sustainable growth. Advantages of the newer plants include standardized designs with shortened construction times; up to 60-year service life; and the possibility of using flexible fuel (including mixed oxide [MOX] fuel). The status of design certification and combined construction and operating license (COL) applications for various new U.S. plants can be found at the NRC Web site (www.nrc.gov).

New reactors being considered in the United States are the advanced passive 1000 (AP1000), economic simplified boiling-water reactor (ESBWR), U.S. evolutionary power reactor (USEPR), advanced boiling-water reactor (ABWR) and U.S. advanced pressurized water reactor (USAPWR). The AP1000 and the ESBWR use passive cooling systems, and the need for safety-related HVAC systems is limited. The ABWR and the USAPWR are enhanced designs of the boiling water reactor and pressurized water reactor, respectively, and HVAC systems for these reactors are not expected to be very much different than those at currently operating BWR and PWR plants. The USEPR is a pressurized water reactor of European design. Brief overviews of HVAC for AP1000, ESBWR, and USEPR plants are as follows.

## Advanced Passive AP1000

HVAC systems at AP1000 plants have several differences from those at pressurized-water reactor plants. The main control room (MCR) has both a normal and an emergency HVAC system. The normal system maintains temperature and relative humidity during normal plant operation, and the emergency system uses passive cooling heat sinks to maintain habitability in the main control room during accident conditions. The normal HVAC system has supplemental air filtration that can be used to filter outdoor air with HEPA and charcoal filters, and maintains the main control room at a slight positive pressure to prevent infiltration of unfiltered air into the main control room envelope. On detection of high radiation in the supply air or an extended loss of ac power, the normal system is isolated and the safety-related emergency habitability system is activated. During emergency-mode operation, air is supplied to the MCR from pressurized storage tanks that are sized to meet the ventilation and pressurization requirements for a 72 h accident event. Passive heat sinks are used in the MCR, instrumentation and control (I&C), and dc equipment rooms to limit temperature rise in those rooms after loss of normal HVAC systems. The heat sinks primarily consist of the thermal mass of concrete in the ceilings and walls. Safety-related HVAC equipment is limited to containment isolation valves, control room isolation valves, and the emergency habitability system. Limiting active safety equipment and using passive safety features is part of the AP1000 design philosophy.

The AP1000 has a containment air filtration system, but it serves no safety-related function and is isolated during accident conditions. It is designed to provide intermittent venting of the containment to the atmosphere during normal plant operation. HVAC systems serving the AP1000 diesel generator, radioactive waste (radwaste), annex, and turbine buildings are similar to those in existing PWRs, with a few exceptions: (1) the containment HVAC recirculation system is non-safety-related; (2) the containment HVAC recirculation system uses chilled water to cool containment; and (3) the diesel generators (and thus the diesel generator building) are not safety related.

## Economic Simplified Boiling-Water Reactor (ESBWR)

ESBWR HVAC systems have several differences from those at operating boiling-water reactor plants. The control building ventilation system has two subsystems: the control building general-area ventilation system (CBGAVS), which serves general areas in the control building, and the control room habitability-area (CRHA) ventilation system (CRHAVS), which serves the main control room. The CRHAVS provides cooling to MCR, which is served by two redundant recirculation air-handling units (AHUs). Recirculation air-handling units in the main control room draw air from the ceiling space plenum, condition it, and discharge it to an underfloor air distribution system. There is an outdoor air AHU for providing makeup to the MCR for normal habitability. During emergency mode, the CRHA is isolated at the boundary by isolation dampers. The recirculation AHU continues to cool while a battery-powered emergency filter unit (EFU) with HEPA and carbon filters provides filtered outdoor air. If power is lost, the EFU continues to operate for pressurization and to maintain the MCR at 30 Pa positive relative to the surroundings for the 72 h accident coping period. During this time, the walls and boundary areas act as passive heat sinks to limit the temperature rise in the main control room.

The reactor building (RB) ventilation system (RBVS) has three non-safety-related subsystems: the contaminated-area ventilation subsystem (CONAVS), refueling and pool-area ventilation subsystem (REPAVS), and the reactor building clean-area ventilation subsystem (CLAVS). These systems are separated from each other with isolation dampers. The CLAVS and CONAVS subsystems are split into separate trains for serving the two halves of the RB. The RBVS has two non-safety-related filter trains (with HEPA and carbon filters), which are backed up with power supply from the diesel generators. Those systems operate on loss of power, but are not credited in the accident analysis. The fuel building ventilation system (FBVS) has two non-safety-related subsystems: the fuel building general-area ventilation subsystem (FBGAVS) and the fuel building fuel-pool-area ventilation subsystem (FBFPVS). The FBGAVS and the FBFPVS subsystems are once-through systems, and room coolers provide supplementary cooling for selected rooms in the fuel building.

The ESBWR uses a centralized non-safety-related chilled-water plant and provides chilled water to various buildings, including the drywell, based on the primary/secondary loop design concept.

## U.S. Evolutionary Power Reactor (USEPR)

Unlike the AP1000 and the ESBWR, the USEPR is not of passive design and is similar to PWR plants, except that the emergency (safety) systems have a four-loop or four-train design: there are four electrical trains of safety systems, four emergency diesels and four loops of safety chilled water. The main control room HVAC system has an active and diverse cooling system consisting of two trains of safety-related water-cooled chillers and two trains of safety-related air-cooled chillers. The main control room air-conditioning system (CRACS) is designed to maintain habitability in the main control room and adjoining rooms during normal operation and during accident conditions involving radiation and toxic gas releases. The CRACS maintains the control room envelope at a 30 Pa positive pressure relative to surrounding areas during accident conditions. The CRACS filtration and air-conditioning equipment and associated ductwork are located inside the control room pressure boundary, thus eliminating the potential for in leakage of unfiltered air. Smoke detectors and toxic gas sensors in the outdoor air supply duct actuate an alarm in the main control room and automatically place the cooling system in recirculation mode.

The containment building ventilation system (CBVS) is composed of three separate subsystems: the (1) non-safety-related full- and low-flow containment purge system, (2) non-safety-related containment filtration system, and (3) safety-related containment cooling system. The containment low-flow purge subsystem operates during normal plant operation to facilitate containment entry and to support outages activities, whereas the full-flow purge system operates only during outages to control the containment environment. The containment filtration subsystem consists of a filter unit with HEPA and carbon filters and a heater, and is used for cleanup of the containment environment. The containment cooling subsystem contains fans, cooling coils, and associated ductwork for cooling various areas of the containment.

### Small Modular Reactor (SMR)

Small Modular Reactors (SMRs) are advanced nuclear fission reactors which are currently in the design and certification process for power generation. In comparison to conventional reactors, SMRs are smaller, simpler and operate with passive systems. They are designed with inherent safety characteristics such as low power and operating pressures and require no human intervention or external power or force to shut them down. The passive systems rely upon natural circulation, convection, gravity, and self-pressurization which significantly reduce the potential for release of radioactivity to the environment during of an accident. Facilities with SMRs have similar ventilation systems as the advanced passive power plants and have no special ventilation requirements other than the bottled air systems for the protection of the operators in the main control room during postulated accident conditions. SMRs have reduced fuel requirements and they require refueling every 3 to 7 years compared 18 to 24 months for conventional nuclear plants.

Currently, various companies in different countries are involved in the design of SMRs and are seeking certification of their design. Some of the SMR projects that are being pursued are the NuScale Light Water SMR and UAMPS, GEH BWRX-300, TerraPower Natrium Reactor, X-Energy Xe-100 Pebble Bed Helium Cooled Gas Reactor, Hotlec International SMR-160 and the Molten Chloride Reactor. In addition to the SMRs, design of Micro-Reactors is also being pursued.

# 4. PLANT HVAC&R SYSTEMS

## 4.1 PRESSURIZED-WATER REACTORS

### Containment Building

**Containment Cooling.** The following systems are typical for containment cooling:

*Reactor containment coolers*. These units remove most of the heat load. Distribution of the air supply depends on the containment layout and the location of the major heat sources.

*Reactor cavity air-handling units or fans*. These units are usually transfer fans without coils that provide cool air to the reactor cavity.

*Control rod or control element drive mechanism (CRDM or CEDM) air-handling units*. The CRDM and CEDM are usually cooled by an induced-draft system using exhaust fans. Because the flow rates, pressure drops, and heat loads are generally high, the air should be cooled before it is returned to the containment atmosphere.

*Essential containment cooling units*. The containment air-cooling system, or a part of it, is normally designed to provide cooling during normal plant operation and after a postulated accident. The system must be able to perform at high temperature, pressure, humidity, and levels of radioactivity. Cooling coils are provided with essential plant service water.

System design must accommodate both normal and accident conditions. The ductwork must be able to endure the rapid pressure build-up associated with accident conditions, and fan motors must be sized to handle the high-density air.

In addition, the system must be analyzed to identify measures to mitigate the effect of water hammer as addressed in NRC’s Generic Letter 96-06.

**Radioactivity Control.** Airborne radioactivity is controlled by the following means:

*Essential air filtration units*. Redundant filter units powered by two Class 1E buses are used to reduce the amount of airborne radioactivity. The typical system consists of a demister, a heater, a HEPA filter bank, and a carbon adsorber, possibly followed by a second HEPA filter bank or by a high-efficiency (90 to 95%) filter bank. The electric heater is designed to reduce the relative humidity of the incoming air from 100% to less than 70%. All the components of the air filtration unit are environmentally qualified (EQ), and designed to meet the requirements of a LOCA.

In the case of an accident and the subsequent operation of the filter train, the carbon can become loaded with radioactive iodine such that the decay heat could cause the carbon to self-ignite if the airflow stops. Heat build-up in the carbon adsorber bed should be evaluated, and an appropriate redundant decay heat removal mechanism should be provided.

*Containment power access purge or minipurge*. Ventilation is sometimes necessary during normal operation, when the reactor is under pressure, to control containment pressure or the level of airborne radioactivity within the containment. The maximum opening size allowed in the containment boundary during normal operation is 200 mm.

The system consists of a supply fan, double containment isolation valves in each of the containment wall penetrations (supply and exhaust), and an exhaust filtration unit with a fan. The typical filtration unit contains a HEPA filter and a carbon adsorber, possibly followed by a second HEPA filter or by a medium-efficiency (90 to 95%) filter bank. The system is non-safety-related, and operates during personnel access into the containment with the reactor under pressure. During normal plant operation, the containment tends toward positive pressure because of air leaks and the exhaust fan is often operated as needed to control pressure inside the containment.

This **minipurge** system should not be connected to any duct system inside the containment. It should include a debris screen within the containment over the inlet and outlet ducts, so that the containment isolation valves can close even if blocked by debris or collapsed ducts.

*Containment refueling purge*. Ventilation is required to control the level of airborne radioactivity during refueling. Because the reactor is not under pressure during refueling, there are no restrictions on the size of the penetrations through the containment boundary. Large openings of 1000 to 1200 mm, each protected by double containment isolation valves, may be provided. The required ventilation rate is typically based on 1 air change per hour.

The system consists of a supply air-handling unit, double containment isolation valves at each supply and exhaust containment penetration, and an exhaust fan. Filters are recommended.

*Containment combustible gas control*. In the case of a LOCA, when a strong solution of sodium hydroxide or boric acid is sprayed into the containment, various metals react and produce hydrogen. Also, if some of the fuel rods are not covered with water, the fuel rod cladding can react with steam at elevated temperatures to release hydrogen into the containment. Therefore, redundant hydrogen recombiners are needed to remove hydrogen from the containment atmosphere, recombine the hydrogen with oxygen, and return the air to the containment. The recombiners may be backed up by special exhaust filtration trains.

## 4.2 BOILING-WATER REACTORS

### Primary Containment

The primary containment HVAC system consists of recirculating cooling units. It normally recirculates and cools the primary containment air to maintain the environmental conditions specified by the NSSS supplier. During an accident, the system may perform a safety-related function of recirculating the air to prevent stratification of any hydrogen that may be generated if the system is credited in the accident analysis. Depending on the specific plant design, the cooling function may or may not be safety related. Primary containment cooling is necessary for maintaining the life of the components inside the containment and for ensuring that the safety temperature limit of the primary containment is maintained during an accident.

Resistance temperature detectors (RTDs) measure containment temperatures at various locations, and provide input into the volumetric average temperature, which is used as the measure of the containment temperature. The plant's technical specification operating limit is established based on the volumetric average temperature. Temperature problems have been experienced in many BWR primary containments because of temperature stratification and underestimation of heat loads. The cooling system should be designed to adequately mix the air to prevent stratification. Heat load calculations should include a safety factor sufficient to allow for deficiencies and degradation in insulation.

### Reactor Building

The reactor building completely encloses the primary containment, auxiliary equipment, and refueling area. Under normal conditions, the reactor building HVAC system maintains the design space conditions and minimizes the release of radioactivity to the environment. The HVAC system consists of a 100% outdoor air cooling system. Outdoor air is filtered, heated, or cooled as required before being distributed throughout the various building areas. The exhaust air flows from areas with the least potential contamination to areas of most potential contamination. Before exhausting to the environment, potentially contaminated air is filtered with HEPA filters and carbon adsorbers; all exhaust air is monitored for radioactivity. To ensure that no unmonitored exfiltration occurs during normal operations, the ventilation systems maintain the reactor building at a negative pressure relative to the atmosphere.

During an event involving a LOCA, MSLB, FHA, or high radiation in the ventilation exhaust, the HVAC system's safety-related function is to isolate the secondary containment consisting of the reactor building and the refueling area. Once isolated by fast-closing valves, the secondary containment boundary functions to contain any leakage from the primary containment or refueling area.

Once the secondary containment is isolated, a safety-related standby gas treatment system (SGTS) is started to reduce the ground level releases by drawing down the secondary containment pressure to about –60 Pa within 120 s. The SGTS exhausts air from the secondary containment to the environment at an elevated release location referred to as the main stack. The SGTS consists of redundant filtration trains, which consist primarily of HEPA filters and carbon adsorbers. The capacity of the SGTS is based on the amount of exhaust air needed to reduce the pressure in the secondary containment and maintain it at the design level, given the containment leakage rates and required drawdown times.

In addition to the SGTS, some designs include safety-related recirculating air systems within the secondary containment to mix, cool, and/or treat the air during accidents. These recirculation systems sometimes use portions of the normal ventilation system ductwork; therefore, if the ductwork is used for that purpose, then it must be classified as safety related.

Other than the emergency core cooling system (ECCS) pump rooms, the isolated secondary containment area is not cooled during accident events. All safety-related components in the secondary containment must be environmentally qualified to operate at the maximum temperature and the temperature profile for the accident event. Safety-related room coolers served by the plant service water provide cooling to the emergency core cooling system (ECCS) pumps during accident conditions.

### Turbine Building

Only a BWR supplies radioactive steam directly to the turbine, which could cause a release of airborne radioactivity to the surroundings. Therefore, areas of the BWR turbine building in which release of airborne radioactivity is possible should be enclosed. These areas must be ventilated and the exhaust filtered to ensure that no radioactivity is released to the atmosphere. Filtration trains are non-safety-related and they typically consist of a prefilter, a HEPA filter, and a carbon adsorber, possibly followed by a second HEPA filter bank or by a medium-efficiency (90 to 95%) filter bank. Filtration requirements and testing are based on the plant and site configuration and commitments for 10 CFR 50, Appendix I requirements. Depending on outdoor air conditions at the location, the turbine building is cooled either with outdoor air or by area coolers served by a dedicated chilled-water system.

## 4.3 HEAVY WATER REACTORS

### Containment Inlet Air-Conditioning/Exhaust Ventilation System

The production of heavy water in sufficient quantities for the needs of a heavy water reactor is complex and expensive. Once produced, however, deuterium oxide ($D_2O$) may be reused indefinitely as long as it does not become contaminated. Because heavy water reactor containments are vented and require makeup air, ordinary water ($H_2O$) is one contaminant that must be contained. This is normally accomplished by means of a non-nuclear safety desiccant air-conditioning unit mounted on the roof of the service building. This unit typically contains a rotary desiccant dryer, hot-water heating coils and chilled-water cooling coils both upstream and downstream of the desiccant wheel, a desiccant regeneration duct containing an electric heater, and a flow control system. The resulting inlet makeup air contains very little moisture. To prevent any radioactive contaminants from escaping up the stack, the containment exhaust ventilation unit typically contains a prefilter bank, a HEPA filter bank, a Type III carbon filter, a second HEPA filter bank, and an exhaust fan.

## 4.4 AREAS OUTSIDE PRIMARY CONTAINMENT

All areas located outside the primary containment are designed to the general requirements contained in ANSI/ANS *Standard* 59.2. These areas are common to any type of plant.

### Auxiliary Building

The auxiliary building contains a large amount of support equipment, much of which handles potentially radioactive material. The building may be air conditioned for equipment protection, and the exhaust is filtered to prevent the release of potential airborne radioactivity. The filtration trains typically consist of a prefilter, a HEPA filter, and a carbon adsorber, possibly followed by a second HEPA filter bank or by a high-efficiency (90 to 95%) filter bank.

The HVAC system is a once-through system, as needed for general cooling. Ventilation is augmented by area or room coolers in the individual equipment rooms requiring additional cooling. The building is maintained at negative pressure relative to the outdoors.

If the equipment in these rooms is not safety related, the area is cooled by normal air-conditioning units. If they are safety related, the area is cooled by safety-related or essential area or room coolers units powered from the same Class 1E (according to IEEE *Standard* 323) power supply as the equipment in the room.

The normal and essential functions may be performed by one cooling unit having both a normal and an essential cooling coil and a safety-related fan served from a Class 1E bus. The normal coil can be a direct-expansion or chilled-water cooling coil served by a normal chilled-water system. The essential coil operates with chilled water from a safety-related chilled-water system or the plant service water, or a safety-related cooling water source.

### Control Room

The control room HVAC system serves the control room habitability zone (those spaces that must be habitable following a postulated accident to allow orderly shutdown of the reactor) and performs the following functions:

- Controls indoor environmental conditions

- Provides pressurization to prevent infiltration
- Minimizes unfiltered in-leakage to the level credited in control room operator dose assessments
- Protects the zone from hazardous chemical fume or particle intrusion
- Protects the zone from fire
- Removes noxious fumes, such as smoke

In defining the control room envelope or pressure boundary, it is necessary to ensure that, in the event of abandonment as a result of fire or smoke in the control room, access to the remote shutdown panel is safeguarded.

Design requirements for the control room HVAC system are outlined in 10 CFR 50, GDC 19 Appendix A, Standard Review Plan Sections 6.4 and 9.4.1, NCR *Regulatory Guides* RG 1.52, 1.78, 1.194, 1.196, and 1.197, and NUREG 0737. In 2003, NRC issued Generic Letter 2003-01 to address control room habitability findings at U.S. nuclear power plants, which suggested that licensees may not have been meeting the control room licensing and design basis, and applicable regulatory requirements, and that existing technical specification surveillance requirements may not have been adequate. As a result, all nuclear plants are required to conduct control room inleakage testing using the tracer gas ($SF_6$) to validate the integrity of the control room boundary and to ensure compliance with dose assessments per GDC 19, Appendix A. It is also necessary to develop and maintain a control room integrity program in accordance with the plant technical specification requirements to control and maintain boundary breaches. Plants are also required to conduct self-assessments of their control room habitability program every three years and inleakage testing every six years. Control room HVAC filter units are designed to filter radioactive contaminants and are fabricated, designed, and tested per ASME *Standards* N509, N510, N511, and AG-1.

## Control Cable Spreading Rooms

These rooms are located directly above and below the control room. They are usually served by an independent ventilating or cooling system or by the air-handling units that serve the electric switchgear room or the control room.

## Diesel Generator Building

Nuclear power plants have an auxiliary or back-up power source for all essential and safety-related equipment in case of loss of off-site electrical power. The auxiliary power source consists of at least redundant diesel generators, each sized to meet the emergency power load. Heat released by the diesel generator and associated auxiliary systems is normally removed by a safety-related ventilation.

## Emergency Electrical Switchgear Rooms

These rooms house the electrical switchgear that controls essential or safety-related equipment. The switchgear located in these rooms must be protected from excessive temperatures (1) to ensure that its qualified life, as determined by environmental qualification, is maintained and (2) to preserve power circuits required for proper operation of the plant, especially its safety-related equipment.

## Battery Rooms

Battery rooms should be maintained at approximately 20 to 25°C for optimum battery capacity and service life. Temperature variations are acceptable as long as they are accounted for in battery sizing calculations. The minimum room design temperature should be taken into account in determining battery capacity. Because batteries produce hydrogen gas during charging periods, the HVAC system must be designed to limit the hydrogen concentration to the lowest of the levels specified by IEEE *Standard* 484, ASHRAE guidelines, OSHA, and the lower explosive limit (LEL) (see Chapter 11 of the 2021 *ASHRAE Handbook—Fundamentals* for more information). The IEEE 1635/ASHRAE *Guideline* 21 recommends limiting hydrogen concentration (by volume) in the battery room to 2% or less. If battery design information is not available, it is recommended that the exhaust system be designed to provide a minimum of five air changes per hour.

## Fuel-Handling Building

New and spent fuel is stored in the fuel-handling building. The building is air conditioned for equipment protection and ventilated with a once-through air system to control potential airborne radioactivity. Normally, the level of airborne radioactivity is so low that the exhaust need not be filtered, although it should be monitored. If significant airborne radioactivity is detected, as can happen during an FHA, the normal building ventilation is isolated and the safety-related system started automatically. The safety-related ventilation system should exhaust through filtration trains powered by Class 1E buses.

### Personnel Facilities

For nuclear power plants, these areas usually include decontamination facilities, laboratories, and medical treatment rooms.

### Pumphouses

Cooling water pumps are protected by houses that are often ventilated by fans to remove the heat from the pump motors. If the pumps are essential or safety related, the ventilation equipment must also be considered safety related.

### Radioactive Waste Building

The building is normally air conditioned for equipment protection and ventilated to control potential airborne radioactivity. The air may require filtration through HEPA filters and/or carbon adsorbers prior to release to the atmosphere.

### Technical Support Center

The technical support center (TSC) is an outside facility located close to the control room. Although normally unoccupied, it is used by plant management and technical support personnel during training exercises and accident events.

The TSC HVAC system is designed to provide the same level of comfort (temperature and humidity) and radiological habitability conditions as provided for the control room. The TSC HVAC system is a non-safety-related system, but is augmented to the same level of importance as the main control room HVAC system. An air filtration system (HEPA, carbon, postfilter) provides the facility protection from radiological releases during an accident. Additional components, such as moisture separators, heaters, and prefilters, are sometimes also used. Because the operation and availability of the TSC is credited in the plant’s emergency operating procedures, the TSC HVAC system should be designed with some redundancy such that maintenance on the HVAC system does not require declaration of the TSC as unavailable. Consult NUREG-0696 for additional information.

## 4.5 NONPOWER MEDICAL AND RESEARCH REACTORS

The requirements for HVAC and filtration systems for nuclear nonpower medical and research reactors are set by the NRC. The criteria depend on the type of reactor (ranging from a nonpressurized swimming pool type to a 10 MW or more pressurized reactor), the type of fuel, the degree of fuel enrichment, and the type of facility and environment. Many of the requirements discussed in the sections on various nuclear power plants apply to a certain degree to these reactors. It is therefore imperative for the designer to be familiar with the NRC requirements for the reactor under design.

## 4.6 LABORATORIES

Requirements for HVAC and filtration systems for laboratories using radioactive materials are set by the DOE and/or the NRC. Laboratories located at DOE facilities are governed by DOE regulations. All other laboratories using radioactive materials are regulated by the NRC. Other agencies may be responsible for regulating other toxic and carcinogenic material present in the facility.

Laboratory containment equipment for nuclear processing facilities is treated as a primary, secondary, or tertiary containment zone, depending on the level of radioactivity anticipated for the area and on the materials to be handled. For additional information see Chapter 17.

### Glove Boxes

Glove boxes are windowed enclosures equipped with one or more flexible gloves for handling material inside the enclosure from the outside. The gloves, attached to a porthole in the enclosure, seal the enclosure from the surrounding environment. Glove boxes permit hazardous materials to be manipulated without being released to the environment.

Because the glove box is usually used to handle hazardous materials, the exhaust is filtered with a HEPA filter before leaving the box and prior to entering the main exhaust duct. In nuclear processing facilities, a glove box is considered primary confinement (see Figure 1), and is therefore subject to the regulations governing those areas. For non-nuclear processing facilities, the designer should know the designated application of the glove box and design the system according to the regulations governing that particular application.

Additional information for glove boxes can be found in documentation published by the American Glovebox Society (AGS).

### Laboratory Fume Hoods

Nuclear laboratory fume hoods are similar to those used in non-nuclear applications. Air velocity across the hood opening must be sufficient to capture and contain all contaminants in the hood. Excessive hood face velocities should be avoided because they cause contaminants to escape when an obstruction (e.g., an operator) is positioned at the hood face. For information on fume hood testing, refer to ASHRAE *Standard* 110.

### Radiobenches

A radiobench has the same shape as a glove box except that in lieu of the panel for the gloves, there is an open area. Air velocity across the opening is generally the same as for laboratory hoods. The level of radioactive contamination handled in a radiobench is much lower than that handled in a glove box.

## 4.7 DECOMMISSIONING NUCLEAR FACILITIES

The exhaust air filtration system for decontamination and decommissioning (D&D) activities in nuclear facilities depends on the type and level of radioactive material expected to be found during the D&D operations. The exhaust system should be engineered to accommodate the increase in dust loading, with more radioactive contamination than is generally anticipated, because the D&D activities dislodge previously fixed materials, making them airborne. Good housekeeping measures include chemical fixing and vacuuming the D&D area as frequently as necessary.

The following are some design considerations for ventilation systems required to protect the health and safety of the public and the D&D personnel:

- Maintain a higher negative pressure in the areas where D&D activities are being performed than in any of the adjacent areas.
- Provide an adequate capture velocity and transport velocity in the exhaust system from each D&D operation to capture and transport fine dust particles and gases to the exhaust filtration system.
- Exhaust system inlets should be as close to the D&D activity as possible to enhance the capture of contaminated materials and to minimize the amount of ductwork that is contaminated. A movable inlet capability is desirable.
- With portable enclosures, filtration of the enclosure inlet and exhaust air must sustain the correct negative internal pressure.

### Low-Level Radioactive Waste

Requirements for the HVAC and filtration systems of low-level radioactive waste facilities are governed by 10 CFR 61. Each facility must have a ventilation system to control airborne radioactivity. The exhaust air is drawn through a filtration system that typically includes a demister, heater, prefilter, HEPA filter, and carbon adsorber, maybe followed by a second filter. Ventilation systems and their CAMs should be designed for the specific characteristics of the facility.

## 4.8 WASTE-HANDLING FACILITIES

The handling of radioactive waste requires inventory control of the different radioactive wastes. See the section on Codes and Standards for pertinent publications.

## 4.9 REPROCESSING PLANTS

A reprocessing plant is a specific-purpose facility. Spent nuclear fuel is opened and the contents dissolved in nitric acid to enable the constituents to be chemically separated and recovered. The offgas contains hazardous chemical and radioactive contaminants. Special cleanup equipment, such as condensers, scrubbers, cyclones, mist eliminators, and special filtration, is required to capture the vapors.

## RESOURCES

Where edition or reaffirmation dates are not listed, the latest date applies.

## AGS

*Guide* 006 - Standard of Practice for the Design and Fabrication of Nuclear Application Gloveboxes
*Guide* 010 - Standard of Practice for Glovebox Fire Protection

## ANS STANDARDS

*Standard* 56.6 - Pressurized Water Reactor Containment Ventilation Systems (ANSI approved; withdrawn)
*Standard* 56.7 - Boiling Water Reactor Containment Ventilation Systems (ANSI approved; withdrawn)
*Standard* 59.2 - Safety Criteria for HVAC Systems Located Outside Primary Containment (ANSI approved; withdrawn)

## AHRI

*Standard* 850 - Performance Rating of Commercial and Industrial Air Filter Equipment (ANSI approved)

## ASHRAE

*Standard* 110 - Method of Testing Performance of Laboratory Fume Hoods (ANSI approved)

## ASME

*Standard* AG-1 - Code on Nuclear Air and Gas Treatment
*Standard* N509 - Nuclear Power Plant Air-Cleaning Units and Components
*Standard* N510 - Testing of Nuclear Air Treatment Systems
*Standard* N511 - In-Service Testing of Nuclear Air Treatment, Heating, Ventilating, and Air-Conditioning Systems
*Standard* NQA-1 - Quality Assurance Program Requirements for Nuclear Facility Applications

## ASTM

*Standard* D3803 - Standard Test Method for Nuclear-Grade Activated Carbon

## CANADIAN STANDARDS

CAN3-N286 Series - Quality Assurance for Nuclear Power Plants
CAN3-N299 Series - Quality Assurance Program Requirements for the Supply of Items and Services for Nuclear Power Plants

## CODE OF FEDERAL REGULATIONS

10 CFR - Title 10 of the Code of Federal Regulations
Part 20 - Standards for Protection Against Radiation
Part 50 - Domestic Licensing of Production and Utilization Facilities
Part 50.69 - Risk-Informed Categorization and Treatment of Structures, Systems and Components for Nuclear Power Reactors
Part 52 - Licenses, Certifications, and Approvals for Nuclear Power Plants
Part 61 - Land Disposal of Radioactive Waste
Part 65 - Requirements for Monitoring the Effectiveness of Maintenance at Nuclear Power Plants
Part 70 - Domestic Licensing of Special Nuclear Material
Part 100 - Reactor Site Criteria
Part 835 - Occupational Radiation Protection

## DOE GUIDES

*Guide* 420.1-1A - Nonreactor Nuclear Safety Design Guide for use with DOE O420.1C, Facility Safety

## DOE HANDBOOKS

HDBK-1132 - Design Considerations
HDBK-1169 - Nuclear Air Cleaning Handbook

## DOE ORDERS

*Order* 420.1 - Facility Safety

## DOE POLICY

*Policy* P 450.4A - Integrated Safety Management Policy

## DOE STANDARDS

*Standard* 1020 - Natural Phenomena Hazards Analysis and Design Criteria for Department of Energy Facilities
*Standard* 1066 - Fire Protection
*Standard* 1128 - Good Practices for Occupational Radiological Protection in Plutonium Facilities
*Standard* 1129 - Tritium Handling and Safe Storage
*Standard* 1168 - Confinement Ventilation and Process Gas Treatment Functional Area Qualification Standard
*Standard* 1189 - Integration of Safety into the Design Process
*Standard* 1269 - Air Cleaning Systems in DOE Nuclear Facilities
*Standard* 3020 - Specification for HEPA Filters Used by DOE Contractors
*Standard* 3025 - Quality Assurance Inspection and Testing of HEPA Filters

## HPS

*Standard* N13.1 - Sampling and Monitoring Releases of Airborne Radioactive Substances from the Stack and Ducts of Nuclear Facilities (ANSI approved)

## ISO STANDARDS

*Standard* 16890 - Air Filters for General Ventilation
ISO 9000 Series - Quality Management Systems

## IEC/IEEE

*Standard* 60780 - Nuclear Facilities—Electrical Equipment Important to Safety—Qualification

## IEEE

*Standard* 344 - Seismic Qualification of Equipment for Nuclear Power Generating Stations
*Standard* 484 - Recommended Practices for Installation Design and Installation of Vented Lead-Acid Batteries for Stationary Applications (ANSI approved)

## IEEE/ASHRAE

*Standard* 1635/
*Guideline* 21 - Guide for the Ventilation and Thermal Management of Batteries for Stationary Applications

## NFPA

*Standard* 90A - Standard for the Installation of Air Conditioning and Ventilating Systems (1999)
*Standard* 90B - Standard for the Installation of Warm Air Heating and Air Conditioning Systems (1999)
*Standard* 91 - Standard for Exhaust Systems for Air Conveying of Vapors, Gases, Mists, and Particulate Solids
*Standard* 92A - Recommended Practice for Smoke Control Systems
*Standard* 204 - Standard for Smoke and Heat Venting
*Standard* 801 - Standard for Facilities Handling Radioactive Materials
*Standard* 803 - Standard for Fire Protection for Light Water Nuclear Power Plants
*Standard* 804 - Standard for Fire Protection for Advanced Light Water Reactor Electric Generating Plants
*Standard* 805 - Performance Based Standard for Fire Protection for Light Water Reactor Electric Generating Plants
*Standard* 806 - Performance Based Standard for Fire Protection for Advanced Nuclear Reactor Electric Generating Plants
*Standard* 901 - Classifications for Incident Reporting and Fire Protection Data

## NRC

NUMARC 93-01 - Industry Guideline for Monitoring the Effectiveness of Maintenance at Nuclear Power Plants
NUREG-0696 - Functional Criteria for Emergency Response Facilities
NUREG-0737 - Clarification of TMI Action Plan Requirements
NUREG-0800 - Standard Review Plans
6.4 - Control Room Habitability System
9.4.1 - Control Room Area Ventilation System
9.4.2 - Spent Fuel Pool Area Ventilation System
9.4.3 - Auxiliary and Radwaste Building Ventilation Systems
9.4.4 - Turbine Area Ventilation System
9.4.5 - Engineered Safety Feature Ventilation System

*Regulatory Guides*

RG 1.140, Rev. 2 - Design, Testing, and Maintenance Criteria for Normal Ventilation Exhaust System Air Filtration and Adsorption Units of LWR Nuclear Power Plants
RG 1.160 - Monitoring the Effectiveness of Maintenance at Nuclear Power Plants
RG 1.189 - Fire Protection for Operating Nuclear Power Plants
RG 1.194 - Atmospheric Relative Concentrations for Control Room Radiological Habitability Assessments at Nuclear Power Plants
RG 1.196 - Control Room Habitability at Light-Water Nuclear Power Reactors
RG 1.197 - Demonstrating Control Room Envelope Integrity at Nuclear Power Reactors
RG 1.201 - Guidelines for Categorizing Structures, Systems, and Components in Nuclear Power Plants According to Their Safety Significance
RG 1.52, Rev. 3 - Design, Testing, and Maintenance Criteria for Engineered Safety Feature Atmospheric Cleanup System Air Filtration and Adsorption Units of LWR Nuclear Power Plants
RG 1.78, Rev. 2 - Assumptions for Evaluating the Habitability of Nuclear Power Plant Control Room During a Postulated Hazardous Chemical Release

*Generic Letters*

96-06 - Assurance of Equipment Operability and Containment Integrity During Design-Basis Accident Conditions
99-02 - Laboratory Testing of Nuclear Grade Activated Charcoal
2003-01 - Control Room Habitability

*Technical Specifications Task Force (TSTF)*

448 - Control Room Habitability

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The preparation of this chapter is assigned to TC 9.2, Industrial Air Conditioning.