CHAPTER 26

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.

BASIC TECHNOLOGY

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.

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 meeting legal requirements, but rather to attaining the lowest cost-effective below-legal levels.

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 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.

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.

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-class must mitigate the effect of any event, accident, or natural catastrophe that may cause the release of radioactivity into the surroundings

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

or the plant atmosphere. These safety systems must be operative at all times. The degree to which an HVAC system contributes to safety determines which components must function during and after a DBA or the simultaneous occurrence of such events as a safe shutdown earthquake (SSE), a tornado, a loss of coolant accident (LOCA), and loss of off-site electrical power (LOSP). Non-safety-related equipment should not adversely affect safety-related equipment.

System Redundancy. Systems important to safety must be redundant and single failure proofed. Such a failure should not cause a failure in the backup 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 (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, acidity, and accumulated radioactivity 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 Z299 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.

Outdoor Conditions

Chapters 27 and 30 of the 2001 *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. U.S. DOE *Order* 6430.1A specifies outdoor conditions.

Nuclear facilities generally consist of heavy structures with high thermal inertia. Time lag should be considered in determining solar 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.

Indoor Conditions

Indoor temperatures are dictated by occupancy, equipment or process requirements, and 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.

Indoor Pressures

Where control of airflow pattern is required, a specific pressure relative to the outside atmosphere or to adjacent areas must be maintained. 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.

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 *Order* O 441.1, or equivalent national regulations of the site country.

Tornado/Missile Protection

Protection from tornados and the objects or missiles launched by wind or other design basis events is normally required to prevent the release of radioactive material to the atmosphere. 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 outside. Tornado dampers are heavy-duty, low-leakage dampers designed for pressure differences in excess of 3 psi. They are normally considered safety-class and are environmentally and seismically qualified.

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 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.

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

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, the location of the safe shutdown panels, the pathway to the safe shutdown panel, and the egress pathway from occupied areas to safe areas.

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

NFPA 90A, 204, and 92A and NUREG 800 SRP Branch Technical Position CMEB 9.5-1 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 the continuous functioning of control room equipment
- Protect personnel from exposure to airborne radioactivity or toxic chemicals potentially present in the outside atmosphere or surrounding plant areas
- Protect personnel from the effects of breaks in high-energy lines in the surrounding plant areas.
- Protect personnel from combustion products emitted from on-site fires

Additional information may be obtained from the Nuclear Energy Institute document entitled Control Room Habitability Assessment Guidance, NEI 99-03.

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., RG 1.52, RG 1.140, ASME AG-1, ASME N509, 10 CFR 20, and 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.

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 meet the relative humidity conditions requisite for carbon filters. 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 deenergized. 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. ARI 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 EN 779 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, Section FC. 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, which is a vapor or gas. Bed depths are typically 2 or 4 in. but may be deeper. These filters have an efficiency of 99.9% for elemental iodine and 95 to 99% for organic iodine. Carbon filters lose efficiency rapidly as the relative humidity increases. They may be preceded by a heating element to keep the relative humidity of the entering air below 70%. 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 ASTM D3803-1989 or latest edition.

Design information for ductwork, housings, fans, dampers, and instrumentation are contained in AG-1, Sections SA, HA, BA, DA, and IA, respectively.

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 6430.1A. Critical items and systems in plutonium processing facilities are designed to confine radioactive materials under both normal and DBA conditions, as required by 10 CFR 100.

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.

Secondary Confinement Zone. This zone is bounded by the walls, floors, roofs, and associated ventilation exhaust systems of the cell or enclosure surrounding the primary confinement zone. Except for glove box operations, this zone is usually unoccupied.

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

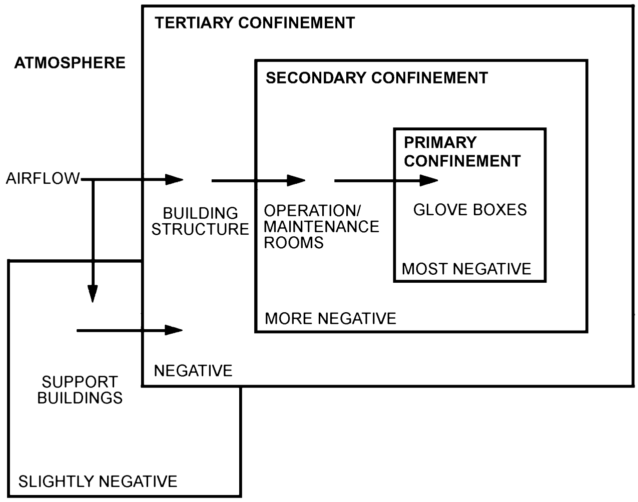

Fig. 1 Typical Process Facility Confinement Categories

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 non-contaminated areas 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 –0.3 to –1.0 in. of water, inert gas glove boxes at –0.3 to –1.5 in., and canyons and cells at a minimum of –1.0 in.

Secondary Confinement. Differential pressures of –0.03 to –0.15 in. of water with respect to the tertiary confinement area are typical.

Tertiary Confinement. Differential pressures of –0.01 to –0.15 in. of water with respect to the atmosphere are typical.

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 outside 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 *Orders* O 420.1 and O 430.1 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 outside.

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 fire fighting. 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
- Carbon bed adsorbers
- Prefilters, postfilters, and HEPA filters
- 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
- Critically safe drain systems
- Tornado 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 windy conditions 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 common tube, usually stainless steel, that leads to a nearby CAM. 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 ANSI *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 non-isokinetic sampling point.
- Maintain fully developed laminar flow at the isokinetic sampling point.
- Ensure fully developed turbulent flow is developed 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.

COMMERCIAL FACILITIES

NUCLEAR POWER PLANTS

The two kinds of commercial light-water power reactors used 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. 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 all normal and emergency modes of plant operation. 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 plants, the specific national rules 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. Three regulatory guides that relate directly to HVAC system design are RG 1.52, RG 1.78, and RG 1.140. Deviations from RG criteria must be justified by the owner and approved by the NRC. Some countries also invoke NRC regulatory guides. Deviations from RG criteria for these cases 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 staff 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 an SAR. The safety review plan is based primarily on the 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 safety limits, limiting conditions for operation, and surveillance requirements 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 AG-1.

Temperature and humidity conditions are dictated by the nuclear steam supply system (NSSS). For U.S. plant designs, these conditions are generally specified for three modes of operation: normal operation, refueling operation, and loss of coolant accident (LOCA) condition:

Normal Operating Condition. Nuclear steam supply system temperature and humidity requirements are specified by the NSSS supplier. Some power plants require recirculation filtration trains in the containment building to control the level of airborne radioactivity. Cooling is provided by a reactor containment cooling system.

Refueling Condition. The maximum allowable temperature during refueling is determined by the refueling personnel. Because they work in protective clothing, their activities are slowed by discomfort, and the refueling outage is prolonged. Cooling can be by normal cooling units because the cooling load is low when the reactor is shut down. Ventilation with outdoor air is necessary.

Loss of Coolant Accident Condition. In the event of a LOCA (breakage of the primary cooling loop), circulating water at high pressure and temperature flashes and fills the containment building with radioactive steam. The major source of radioactivity is iodine in the water. The primary measures taken are directed at reducing the pressure in the containment building and lowering the amount of radioactive products in the containment atmosphere. Pressure is reduced by the reactor containment cooling units and/or sprays, which cool the atmosphere and condense the steam.

References to standards and regulatory documents in the following section reflect U.S. practice. For plants outside the United States, the specific countries' national codes and standards are applicable.

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.

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. 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.

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.

Gas-Cooled Reactors

Gas-cooled reactors are primarily used in the United Kingdom. There are two types: Magnox reactors, which use natural uranium metal fuel clad in a magnesium oxide can, and advanced gas-cooled reactors (AGRs), which use slightly enriched uranium oxide fuel in stainless steel with a graphite sleeve.

Russian Reactor Types

VVER Reactors. These are pressurized water reactor systems, similar in many respects to Western PWR designs. A major difference is that the VVER steam generators are horizontal rather than vertical. Besides in Russia, VVER plants are operating in several Eastern European countries and are being built in China and India.

RBMK Reactors. The original Russian reactor design consists of a large graphite block with horizontal pressure tubes similar to the Magnox design. The system is a hybrid of a graphite-moderated and water-cooled design, making the physics of RBMKs very complex.

Advanced Reactor Types

There are a number of proposed advanced reactor systems being studied. Most use passive safety systems that do not rely on mechanical or electromechanical devices being activated in a particular sequence. Future nuclear plant construction will be based on this type of design.

PLANT HVAC&R SYSTEMS

PRESSURIZED WATER REACTORS

Reactor 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 reactor containment cooling units. The containment air-cooling system, or a part of it, is normally designed to provide cooling 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 service water.

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

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

Essential containment air filtration units. Some older power plants rely on redundant filter units powered by two Class 1E buses to reduce the amount of post-LOCA 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 must be designed and manufactured to meet the requirements of a LOCA environment.

In the case of a LOCA and the subsequent operation of the filter train, the carbon becomes loaded with radioactive iodine such that the decay heat could cause the carbon to self-ignite if the airflow stops. If the primary fan stops, a secondary fan maintains a minimum airflow through the carbon bed to remove the heat generated by the radioactive decay. The decay heat fan is powered by a Class 1E power supply. The filtration units are located inside the containment.

Containment power access purge or minipurge. Ventilation is 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 8 in.

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 high-efficiency (90 to 95%) filter bank.

This 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 42 to 48 in., 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 the air from the containment atmosphere, recombine the hydrogen with the oxygen and return the air to the containment. The recombiners may be backed up by special exhaust filtration trains.

BOILING WATER REACTORS

Primary Containment

The primary containment HVAC system consists of recirculating cooler units. It normally recirculates and cools the primary containment air to maintain the environmental conditions specified by the NSSS supplier. In an accident, the system performs the safety-related function of recirculating the air to prevent stratification of any hydrogen that may be generated. Depending on the specific plant design, the cooling function may or may not be safety related.

Temperature problems have been experienced in many BWR primary containments due to temperature stratification and underestimation of heat loads. The ductwork should adequately mix the air to prevent stratification. Heat load calculations should include a safety factor sufficient to allow for deficiencies in insulation installation. In addition, a temperature-monitoring system should be installed in the primary containment to ensure that bulk average temperature limits are not exceeded.

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% outside air cooling system. Outside 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.

Upon detection of abnormal plant conditions, such as a line break, high radiation in the ventilation exhaust, or loss of negative pressure, the HVAC system's safety-related function is to isolate the reactor building. Once isolated by fast-closing, gastight isolation valves, the reactor building serves as a secondary containment boundary. This boundary is designed to contain any leakage from the primary containment or refueling area following an accident.

Once the secondary containment is isolated, pressure rises due to the loss of the normal ventilation system and the thermal expansion of the confined air. A safety-related exhaust system, the standby gas treatment system (SGTS), is started to reduce and maintain the building's negative pressure. The SGTS exhausts air from the secondary containment to the environment through a filtration train consisting 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 accident conditions. These recirculation systems use portions of the normal ventilation system ductwork; therefore, the ductwork must be classified as safety related.

If the isolated secondary containment area is not to be cooled during accident conditions, it is necessary to determine the maximum temperature that could be reached during an accident. All safety-related components in the secondary containment must be environmentally qualified to operate at this temperature. In most plant designs, safety-related unit coolers handle the high heat release with emergency core cooling system (ECCS) pumps.

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 surrounding atmosphere. 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. Filtration requirements are based on the plant and site configuration.

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 only a very few grains of 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.

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 local recirculation air-handling units in the individual equipment rooms requiring additional cooling due to localized heat loads. The building is maintained at negative pressure relative to the outside.

If the equipment in these rooms is not safety related, the area is cooled by normal air-conditioning units. If it is safety related, the area is cooled by safety-related or essential air-handling 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 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 chilled-water or direct-expansion cooling coil. Chilled water for the normal coil is served by a normal chilled-water system. The essential coil operates with chilled water from a safety-related chilled-water system.

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 the orderly shutdown of the reactor) and performs the following functions:

- Controls indoor environmental conditions
- Provides pressurization to prevent infiltration
- Reduces the radioactivity of the influent
- Protects the zone from hazardous chemical fume intrusion
- Protects the zone from fire
- Removes noxious fumes, such as smoke

The design requirements are described in detail in SRP 6.4 and SRP 9.4.1. Regulatory guides that directly affect control room design are RG 1.52, RG 1.78, and RG 1.95. NUREG-CR-3786 provides a summary of the documents affecting control room system design. ASME *Standards* N509 and AG-1 also provide guidance for the design of control room habitability systems and methods of analyzing pressure boundary leakage effects.

Control Cable Spreading Rooms

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

Diesel Generator Building

Nuclear power plants have auxiliary power plants to generate electric power for all essential and safety-related equipment in case of loss of off-site electrical power. The auxiliary power plant consists of at least two independent diesel generators, each sized to meet the emergency power load. The heat released by the diesel generator and associated auxiliary systems is normally removed through outside air 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 useful life, as determined by environmental qualification, is not cut short 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 77°F with a temperature gradient of not more than 5°F, according to IEEE *Standard* 484. The minimum room design temperature should be taken into account in determining battery size. 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, OSHA, and the lower explosive limit (LEL). The minimum number of room air changes per hour is five. Because hydrogen is lighter than air, the system exhaust duct inlet openings should be located on the topside of the duct to prevent hydrogen pockets from forming at the ceiling. If the ceiling is supported by structural beams, there should be an exhaust air opening in each beam pocket.

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, the building is sealed and kept under negative pressure by exhaust through filtration trains powered by Class 1E buses.

Personnel Facilities

For nuclear power plants, this area usually includes 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 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 accidents.

The TSC HVAC system is designed to provide the same comfort (temperature and humidity) and radiological habitability conditions maintained in the control room. The system is generally designed to be non-nuclear safety related. An outside air filtration system (HEPA carbon postfilter) pressurizes the facility with filtered outside air during emergency conditions. Additional components, such as moisture separators, heaters, and prefilters, are sometimes also used.

GAS-COOLED REACTOR HVAC SYSTEMS

Magnox reactors have a simple HVAC system that provides once-through cooling. Air is drawn from surrounding areas into the space between the biological/thermal shield and the pressure vessel. This cascaded air is routed so as to cool areas of the biological/thermal shield, charge tubes, irradiation tubes, top dome, CO_2 ducting, and other annulus voids. The air is normally extracted with fans and discharged directly to atmosphere without filtration. Iodine filtration can be switched in-line if activity is detected in the extract flow. Other parts of the building, such as the charge hall, discharge well, and turbine hall, have their own supply and extract systems.

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 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.

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 14, Laboratories.

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 nonnuclear 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.

Laboratory Fume Hoods

Nuclear laboratory fume hoods are similar to those used in nonnuclear 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.

DECOMMISSIONING OF 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.

WASTE HANDLING FACILITES

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

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 off-gas 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.

CODES AND STANDARDS

ANSI

Standard N13.1	Guide for Sampling Airborne Radioactive Materials in Nuclear Facilities

ANSI/ANS

Standard 56.6-1986	Pressurized Water Reactor Containment Ventilation Systems
Standard 56.7-1987	Boiling Water Reactor Containment Ventilation Systems
Standard 59.2	Safety Criteria for HVAC Systems Located outside Primary Containment

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 NQA-1	Quality Assurance Program Requirements for Nuclear Facility Applications

ANSI/ASHRAE

Standard 110	Method of Testing Performance of Laboratory Fume Hoods
10 CFR	Title 10 of the *Code of Federal Regulations*
Part 20	Standards for Protection Against Radiation (10 CFR 20)
Part 50	Domestic Licensing of Production and Utilization Facilities (10 CFR 50)
Part 61	Land Disposal of Radioactive Waste (10 CFR 61)
Part 100	Reactor Site Criteria (10 CFR 100)
Part 835	Occupational Radiation Protection (10 CFR 835)

ASTM

Standard 3803-1989	Standard method for radioiodine testing of nuclear-grade gas-phase adsorbents

DOE Orders

DOE *Order* O 420.1	Facility Safety
DOE *Order* O 430.1	Life cycle asset management
DOE *Order* 6430.1A	General Design Criteria
DOE *Order* O 441.1	Radiation Protection of the Public and the Environment

DOE Standards

DOE *Standard* 3020	Specification for HEPA Filters Used by DOE Contractors
DOE *Standard* 3025	Quality Assurance Inspection and Testing of HEPA Filters

ANSI/IEEE

Standard 323	Standard for Qualifying Class 1E Equipment for Nuclear Power Generating Stations
Standard 484	Recommended Practice for Installation Design and Installation of Vented Lead-Acid Batteries for Stationary Applications

NFPA

NFPA 90A	Standard for the Installation of Air Conditioning and Ventilating Systems (1999)
NFPA 90B	Standard for the Installation of Warm Air Heating and Air Conditioning Systems (1999)
NFPA 92A	Recommended practice for smoke control systems (2000)
NFPA 204	Standard for Smoke and Heat Venting (2002)
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 901	Classifications for Incident Reporting and Fire Protection Data

ARI

Standard 850	Commercial and Industrial Air Filter Equipment

U.S. Nuclear Regulatory Commission

NUREG-0696	Functional Criteria for Emergency Response Facilities
NUREG-0800	Standard Review Plans
SRP 6.4	Control Room Habitability Systems
SRP 9.4.1	Control Room Area Ventilation System
SRP 9.4.2	Spent Fuel Pool Area Ventilation System
SRP 9.4.3	Auxiliary and Radwaste Building Ventilation Systems
SRP 9.4.4	Turbine Area Ventilation System
SRP 9.4.5	Engineered Safety Feature Ventilation System
NUREG-CR-3786	A Review of Regulatory Requirements Governing Control Room Habitability
Regulatory Guides	U.S. Nuclear Regulatory Commission
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. 1	Assumptions for Evaluating the Habitability of Nuclear Power Plant Control Room during a Postulated Hazardous Chemical Release
RG 1.95	Protection of Nuclear Power Plant Control Room Operators against Accidental Chlorine Release
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 1.189	Fire Protection for Operating Nuclear Power Plants

Canadian Standards

CAN3-N286 Series	Quality Assurance for Nuclear Power Plants
CAN3-Z299	Quality Assurance Programs

European Standards

EN 779	Particulate Air Filters for General Ventilation—Requirements, Testing, Marking