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NUCLEAR FACILITY DESIGN CONSIDERATIONS - VOL 1 OF 3

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NUC-113 EXAM PREVIEW

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Exam Preview:

1. Breaches in the primary confinement barrier that cannot be totally avoided or ruled out (e.g., due to glove or seal failure) should be compensated for by providing adequate inflow of air or safe collection of spilled liquid.
   a. True
   b. False
2. Typical factors that affect confinement system design are the type, quantity, form, and conditions for dispersing the hazardous material, including the type and severity of potential accidents. Which of the following is an example of a secondary confinement system?
   a. Tanks and associated piping that contain hazardous material
   b. Off gas system that controls effluent from within the primary confinement
   c. Ventilation exhaust system of the facility
   d. Ventilation exhaust system of the enclosure surrounding the equipment
3. According to the reference material, generally, Uranium Conversion and Recovery Facilities (UCRFs) have used three confinement systems.
   a. True
   b. False
4. According to the reference material, if room air is recirculated, the recirculation circuit should provide at least __ stage(s) of HEPA filtration. The design should include redundant filter banks and fans.
   a. 1
   b. 2
   c. 3
   d. 4

5. Metallurgical processing equipment should have dedicated ventilation systems that exhaust to a common, final filtration train. If airborne particle capture is required, a high linear velocity will be necessary to ventilate these process areas due to the greater densities of metal particles.
    a. True
    b. False
6. According to the reference material, control rooms should also be protected from the entry of smoke or other toxic gases through ventilation air intakes. Alternatively, ___ intakes, separately located, could lessen the likelihood of toxic gas intake.
    a. 1
    b. 2
    c. 3
    d. 4
7. Using the Reference section of the reference material, which of the following DOE Orders and Standards is used when examining Facility Safety?
    a. DOE O 420.1C
    b. DOE-HDBK-1169-2003
    c. DOE-STD-1066-2012
    d. DOE-STD-1098-2008 (CN1)
8. According to the reference material, generally, facilities that process and handle unirradiated enriched uranium (UEU) have used __ confinement systems.
    a. N/A
    b. 1
    c. 2
    d. 3
9. Separate exhaust ventilation system ductwork and the initial two stages of filtration should be designed for exhaust air from enclosures that confine the process (e.g., gloveboxes). These systems should maintain a positive pressure inside the enclosure with respect to the operating area.
    a. True
    b. False
10. Using the Reference section of the reference material, which of the following documents/standards is used when examine or implementing Process Piping?
    a. ACI 224.1 R-07
    b. ASME NQA-1
    c. ASTM D4258-05
    d. ASME B31.3-2012

ACRONYMS

ACGIH	American Conference of Governmental Industrial Hygienists
ACI	American Concrete Institute
ADP	automated data processing
AHJ	authority having jurisdiction
ALARA	as low as reasonably achievable
ANS	American National Standards
ANSI	American National Standards Institute
ASHRAE	American Society of Heating, Refrigerating, and Air Conditioning Engineers
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing & Materials
AWG	American wire gauge
AWS	American Welding Society
BP&V	Boiler and Pressure Vessel
CAD	computer-aided design
CADD	computer-aided design and drafting
CAM	continuous air monitors
CFR	Code of Federal Regulations
D&D	decontamination and decommissioning
DC	direct current
DCS	distributed control system
DNFSB	Defense Nuclear Facilities Safety Board
DOE	Department of Energy
DOE-EM	Department of Energy, Office of Environmental Management
DOE-RW	Department of Energy, Office of Civilian Radioactive Waste Management
dpm	disintegrations per minute
ER	environmental remediation
FIPS	Federal Information Processing Standards
HEPA	high-efficiency particulate air (filter)
HID	high-intensity discharge
HPS	high-pressure sodium
HVAC	heating, ventilation, and air conditioning
I/O	input/output
IAEA	International Atomic Energy Agency
IEEE	Institute of Electrical and Electronics Engineers
IFM	irradiated fissile material
IFMSF	irradiated fissile material storage facility
ISA	International Society for Measurement and Control (formerly Instrument Society of America)
LET	linear energy transfer
MIC	microbiological-influenced corrosion
NFC	National Fire Code
NFPA	National Fire Protection Association
NPH	natural phenomena hazards

NRC	Nuclear Regulatory Commission
PLC	programmable logic controller
PPHF	plutonium processing and handling facility
PSF	plutonium storage facility
plf	pounds per linear foot
ppm	parts per million
psf	pounds per square foot
psi	pounds per square inch
psia	pounds per square inch absolute
psig	pounds per square inch gauge
PTFE	polytetraflouoroethylene
PVC	polyvinyl chloride
R.G.	Regulatory Guide
RLWF	radioactive liquid waste facility
RSWF	radioactive solid waste facility
SNM	special nuclear material
SSC	structures, systems, and components
SST	safe, secured transport
STP	standard temperature and pressure
TSR	technical safety requirement
UCRF	uranium conversion and recovery facilities
UEU	unirradiated enriched uranium
UEUSF	unirradiated enriched uranium storage facility
UMTRA	Uranium Mill Tailings Remedial Action
UPHF	uranium processing and handling facility
UPS	uninterrupted power supply

ABBREVIATIONS

Ω	resistivity
µm	micron
^oC	degrees Centigrade
^oF	degrees Fahrenheit
^oK	Kelvin
Ar	argon
cal	calorie
Ci	curie
cm^2	square centimeter
cm^3	cubic centimeter
D	deuterium
g	gram
H	hydrogen
H_2O	water
keV	kiloelectron volt (joule)
kVA	kilovolt-ampere
kWh	kilowatt-hour
mCi	millicurie (becquerel)
m^3	cubic meter

mg	milligram
min	minute
mm	millimeter
MW(e)	megawatt (electrical)
N_2O	nitrous oxide
N_2	nitrogen
NO	nitric oxide
NO_2	nitrogen dioxide
O_2	oxygen
Pu(IV)	plutonium polymer
Pu^{238}	plutonium-238
PuF_4	plutonium tetrafluoride
sec	second
T	tritium (the hydrogen isotope of mass-3)
UF_6	uranium hexafluoride
UO_2	uranium oxide

PART I: DESIGN CONSIDERATIONS

INTRODUCTION

Scope. The Design Considerations Handbook includes information and suggestions for the design of systems typical to nuclear facilities, information specific to various types of special facilities, and information useful to various design disciplines.

The handbook is presented in two parts.

Part I, which addresses design considerations, includes two sections. The first addresses the design of systems typically used in nuclear facilities to control radiation or radioactive materials. Specifically, this part addresses the design of confinement systems, and radiation protection and effluent monitoring systems. The second section of Part I addresses the design of special facilities (i.e., specific types of nonreactor nuclear facilities). The specific design considerations provided in this section were developed from review of DOE 6430.1A, *General Design Criteria*, and are supplemented with specific suggestions and considerations from designers with experience designing and operating such facilities.

Part II of the Design Considerations Handbook describes good practices and design principles that should be considered in specific design disciplines, such as mechanical systems and electrical systems. These good practices are based on specific experiences in the design of nuclear facilities by design engineers with related experience. This part of the Design Considerations Handbook contains five sections, each of which applies to a particular engineering discipline.

Purpose. The purpose of this handbook is to collect and retain the non-mandatory Department of Energy (DOE) good practices from DOE 6430.1A and to supplement those practices with additional lessons learned.

Applicability. This handbook is a reference document that may be consulted during design of nonreactor nuclear facilities. Its provisions are not to be invoked as requirements. Because design requirements are treated in DOE O 420.1C and because the material in the handbook is not a complete and exhaustive collection of material that a designer would need, the contents of this handbook are not intended to be referenced as requirements. Guidance in this handbook should not be used as justification of acceptable ways of satisfying requirements. The adequacy of a design should stand on its own merits.

SECTION 1

SYSTEMS

This section of the handbook treats systems (e.g., confinement systems, radiation protection, and effluent monitoring and controls) typically used in nuclear facilities to control radiation or radioactive material. The specifics of designing these systems are developed in an iterative fashion by considering hazards and opportunities (alternatives) for prevention and mitigation of accidents involving the hazards. This section provides information based on experience, which the designer may use when developing the design.

1.1 CONFINEMENT SYSTEMS

1.1.1 **Introduction and Scope.** Safety ventilation and off-gas systems are generally designed to operate in conjunction with physical barriers to form a confinement system that limits the release of radioactive or other hazardous material to the environment and prevents or minimizes the spread of contamination within the facility. Confinement systems should be designed to—

- prevent (if possible) or minimize the spread of radioactive and other hazardous materials to occupied areas;
- minimize the release of radioactive and other hazardous materials in facility effluents during normal operation and anticipated operational occurrences;
- minimize the spread of radioactive and other hazardous materials within unoccupied process areas; and
- limit the release of radioactive and other hazardous materials resulting from accidents, including those caused by severe natural phenomena and man-made events.

The specifics of confinement system design, as they relate to a particular facility, should be guided by an iterative process between safety analyses and design. Safety analyses define the functional requirements of the design, such as the type and severity of accident conditions to be accommodated by the confinement system. The design should also consider sources of functional design requirements including maintenance, operability, and process requirements. This section discusses primary, secondary, and tertiary confinement systems, design of confinement ventilation systems, and aspects of confinement system design by nuclear facility type. The American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE) *HVAC Applications Handbook* provides general information regarding heating, ventilation, and air conditioning (HVAC) design for confinement systems.

1.1.2 **General Considerations.** Confinement system features, including confinement barriers and associated ventilation systems, are used to maintain controlled, continuous airflow from the environment into the confinement building, and then from uncontaminated areas of the building to potentially contaminated areas, and then to normally contaminated areas.

For a specific nuclear facility, the number and arrangement of confinement barriers and their design features and characteristics are determined on a case-by-case basis. Typical factors that affect confinement system design are the type, quantity, form, and conditions for dispersing the hazardous material, including the type and severity of potential accidents. In addition, alternative process and facility design features may reduce potential hazards and the resulting requirements for confinement system design. Engineering evaluations, trade-offs, and experience are used to develop a practical design that achieves confinement system objectives.

Because the number and arrangement of confinement systems required for a specific nuclear facility design cannot be predicted, this discussion describes a conservative confinement system design that uses the three principal confinement systems described below. The discussion assumes that three levels of confinement are necessary or justified. Design decisions for a specific facility should address that facility's hazards and other factors.

- Primary confinement is usually provided by piping, tanks, gloveboxes, encapsulating material, and the like, and any off-gas system that controls effluent from within the primary confinement. It confines hazardous material to the vicinity of its processing.
- Secondary confinement is usually provided by walls, floors, roofs, and associated ventilation exhaust systems of the cell or enclosure

surrounding the process material or equipment. Except for glovebox operations, the area inside this barrier provides protection for operating personnel.

- Tertiary confinement is provided by the walls, floor, roof, and associated ventilation exhaust system of the facility. Tertiary confinement provides a final barrier against release of hazardous material to the environment.

1.1.3 **Primary Confinement System.** Primary confinement consists of barriers, enclosures, gloveboxes, piping, vessels, tanks, and the like that contain radioactive or other hazardous material. Its primary function is to prevent release of radioactive or hazardous material to areas other than those in which processing operations are normally conducted.

Primary confinement of processes that involve readily dispersible forms of material (e.g., solutions, powder or small fragments, gases) is provided by gloveboxes or other confining enclosures. Hoods are used when hazards are acceptably low, as indicated by the quantity of the material involved, the specific operation to be performed, and the hazardous nature and chemical form of material involved. The confinement philosophy described below should be applied to any component that serves a primary confinement function, such as conveyor systems, material transfer stations, and ventilation/off-gas systems.

Breaches in the primary confinement barrier that cannot be totally avoided or ruled out (e.g., due to glove or seal failure) should be compensated for by providing adequate inflow of air or safe collection of spilled liquid. Occasional breaches required for anticipated maintenance should be made only under carefully controlled conditions. Primary confinement should provide for storage of in-process material elsewhere, temporary alternative barriers, and adequate inflow of air to provide contamination control.

The supply and exhaust ventilation system should be sized to maintain in-facility radiation doses at levels as low as reasonably achievable (ALARA) in the event of the largest credible breach. Process equipment and the process itself should be designed to minimize the probability of fire, explosion, or corrosion that might breach the confinement barrier. When handling pyrophoric forms (e.g., chips, filings, dust) of materials in the confinement enclosure, the guidance of DOE-

HDBK-1081-94, *Primer on Spontaneous Heating and Pyrophoricity,* should be considered. Halon systems should not be used with pyrophoric metals due to the oxidizing reaction between halon and hot metal.

Primary confinement barrier(s) should be provided between the process material and any auxiliary system (e.g., a cooling system) to minimize risk of material transfer to an unsafe location or introduction of an undesirable medium into the process area. Differential pressure across the barrier(s) should be used where appropriate.

The effectiveness of each confinement barrier should be checked analytically against challenges it is expected to withstand without loss of function. This applies to any form of the hazardous material (gas, liquid, or solid) and its carrying medium (i.e., airborne or spilled in a liquid).

To protect the integrity of process confinement systems, fire protection systems should include the following features:

- Automatic and redundant fire detection devices.
  - A fire-extinguishing system that actuates automatically to rapidly remove heat produced by fire to prevent or minimize pressurization of a process confinement and
  - rapidly extinguish a fire to minimize the loading of ventilation system filters with combustion products.

(See DOE-STD-1066-2012, *Fire Protection*, and DOE-STD-3020-2005, *Specifications for HEPA Filters Used by DOE Contractors.)*

- The introduction of the extinguishing agent in a way that does not result in overpressurization of the confinement barriers.
- Provisions to collect liquid agents when a wet suppression agent is used.

Enclosures (as primary confinement). Enclosures are physical barriers (e.g., cells, cubicles, gloveboxes, fume hoods, conveyor tunnels) that, together with their ventilation and operating systems, prevent the release of radioactive or other hazardous material to the work space or the environment. Accordingly, their structural and confinement integrity is a design consideration. [See the American Conference of Governmental Industrial Hygienists (ACGIH) *Industrial Ventilation: A Manual of Recommended Practice* *for Design* (ACGIH 2097); American Society of Mechanical Engineers (ASME) *Code on Nuclear Air and Gas Treatment* (ASME AG-1); and the *Nuclear Air Cleaning Handbook* (DOE-HDBK-1169-2003).]

Enclosures should be designed to prevent exposure of personnel to airborne contamination and to implement ALARA concepts to minimize operator exposures. The enclosure system, including its internal and external support structures, should therefore be designed to withstand the effects of normal operating conditions, anticipated events, and accidents. Criticality considerations, when needed, should include water or other liquid sources, potential liquid level in the enclosure (during operations or fire fighting), drains to limit liquid level in the enclosure, and liquid collection in depressions, walls, and other areas.

The following additional considerations should be addressed in designing enclosures:

- Where practical, equipment not functionally required to operate directly in the presence of radioactive materials should be located outside the enclosure. Equipment located within the enclosure should be designed to allow for in-place maintenance and/or replacement.
- The design and operation of support and protection systems, such as fire protection, should not promote the failure of the enclosure system integrity or the loss of confinement.
- Noncombustible or fire-resistant, corrosion-resistant materials should be used for enclosures and, to the maximum extent practicable, for any required radiation shielding. In no case should the total combustible loading located in a fire area exceed the fire resistance rating of the structural envelope. (See National Fire Protection Association (NFPA) *Fire Protection Handbook* for guidance on the relationship of combustible loading versus fire resistance rating.)
- In conjunction with their ventilation systems, enclosures should be capable of maintaining confinement (i.e., negative pressure with respect to the surrounding operating area).
- To reduce migration of contamination, closure devices or permanent seals should be provided on entrances to and exits from piping, ducts, or conduits penetrating confinement barriers. Such closures or seals should have an integrity equal to or greater than the barrier itself.

- Where pertinent to safety, enclosure design should consider heat generation in the enclosure. Such heat sources may be from processes, lighting, chemical reactions, and the decay of radioactive material. Consideration of radioactive material as a heat source is particularly applicable to storage enclosures.
- Consideration should be given to modular construction, versatility, relocation, and incorporation of shielding. Structural support should be provided to accommodate any anticipated loading resulting from shielding. The type of shielding used and its placement should allow for adequate fire-fighting access.

Enclosure specifications should address the following standardized features, where applicable:

- Windows and mountings.
  - Windows should be appropriately sized (and as small as practicable) and located to provide operators with visual access to the enclosure interior.
  - Windows should be constructed of noncombustible or approved fire-resistant materials.
  - Resistance of the selected material to impact and radiation damage should be considered.
  - The use of Mylar ™ glass laminates should be considered for use as viewing windows and lighting fixture covers in hydrofluoric acid environments.
  - Windows should be designed to minimize the risk of releasing contamination to the working area during window replacement.
  - Window material should be selected based on specific process, combustible loading, and radiological safety considerations.
- Glove ports (size, location, and height).
  - Glove ports should be located to facilitate both operations and maintenance work inside the enclosure.
  - Gloves should be flexible enough for operating personnel to access interior surfaces and equipment.

  - Gloves should be designed to allow replacement without losing contamination control and with minimum exposure to the operator.
  - When gloves are not in place, a noncombustible shield or cover for each glove port should be provided.
- Exhaust air filters to minimize contamination of ductwork.
- Ease of cleaning (radius corners, smooth interior and exterior surfaces, minimal protuberances, and accessibility of all parts).
- Specific coatings for boxes containing halides to permit long life and ease of decontamination.
- Adequate interior illumination (from fixtures mounted on the exterior where feasible).
- Connections for service lines, conduits, instrument leads, drains, and ductwork.
- Pressure differential monitors and heat detection.
- Fire barriers and filter installation.
- Sample removal ports for filter testing.

Consideration should be given to incorporating transfer systems (such as double-door, sealed transfer systems or chain conveyors) for removal of hazardous material from a glovebox. These systems are designed to allow entry and removal of material without breaching the integrity of the glovebox. (See DOE-HDBK-1169-2003, *Nuclear Air Cleaning Handbook,* for additional information.)

1.1.4 **Secondary Confinement.** The secondary confinement system consists of confinement barriers and associated ventilation systems that confine any potential release of hazardous material from primary confinement. For example, when gloveboxes provide primary confinement for radioactive or hazardous material processing, the functional requirements for secondary confinement refer to the operating area boundary and the ventilation system serving the operating area.

Design features incorporated into the secondary confinement system should have been proven effective by extensive experience in similar applications or by formal prototype testing. Such design features include the following:

- Continuous monitoring capability should be provided to detect loss of proper differential pressure with respect to the process area. Operating areas should also be continuously monitored. Commensurate with the potential hazards, consideration should be given to the use of redundant sensors and alarms.
- Permanent penetrations of the secondary confinement (e.g., pipes, ducts) should have positive seals or isolation valves or double closure with controlled secondary to primary leakage on pass-through penetrations (e.g., personnel air locks and enclosed vestibules).
- Ventilation systems associated with secondary confinement should be designed with adequate capacity to provide proper direction and velocity of airflow in the event of the largest credible breach in the barrier.
- Secondary and tertiary barriers may exist in common such as a single structural envelope (e.g., walls, roof slab, floor slab), provided the barrier can withstand the effects of external events, and does not contain access ways that allow the routine transfer of personnel, equipment, or materials directly to the exterior of the facility. Access ways into the interior of the single structural envelope should be designed so that the access way is entered from another level of confinement.
- Special features (e.g., air locks, enclosed vestibules) should be considered for access through confinement barriers to minimize the impact of facility access requirements on the ventilation system and to prevent the release of radioactive airborne materials.
- The use of stack-vented rupture disks, seal pots, or bubbler traps should be considered to prevent overpressurization and potential explosive disruption of the secondary confinement system.
- When a pipe is used as the primary confinement barrier for materials, and the pipe exits a secondary confinement, the secondary confinement should be provided by a double-walled pipe of other encasement. In areas within the facility, the use of double-walled pipe should be considered. Leakage monitoring should be provided to detect leakage into the space between the primary pipe and the secondary confinement barrier. (See Resource Conservation and Recovery Act requirements in 40 Code of Federal Regulations (CFR) 264.193,

Containment and Detection of Releases, and 40 CFR 265.193, *Containment and Detection of Releases.*)

- When primary confinement includes ductwork, the considerations in the previous bullet should be applied to the ductwork. Transition from primary to secondary confinement typically occurs downstream of air cleaning devices, such as high-efficiency particulate air (HEPA) filters and adsorbers.

1.1.5 **Tertiary Confinement.** Tertiary confinement is provided by the building or outer structure of the facility. For some accidents, it represents the final barrier to release of hazardous material to the environment; for others, it is a barrier that protects other parts of the facility from damage.

ALARA concepts should be incorporated in tertiary confinement system design to minimize exposure to operators, the public, and the environment.

1.1.6 **Confinement Ventilation Systems.** The design of a confinement ventilation system ensures the desired airflow at all times and specifically when personnel access doors or hatches are open. When necessary, air locks or enclosed vestibules may be used to minimize the impact of open doors or hatches on the ventilation system and to prevent the spread of airborne contamination within the facility.

Air cleanup systems provided in confinement ventilation exhaust systems are typically used to limit the release of radioactive or other hazardous material to the environment and to minimize the spread of contamination within the facility. To the extent practical, discrete processing steps should be performed in individual process confinements to reduce the amount of hazardous material that can be released by a single or local failure of the confinement system. The following general cleanup system features should be considered, as appropriate, for ventilation system design:

- The level of radioactive material in confinement exhaust systems should be continuously monitored. Alarms should annunciate when activity levels above specified limits are detected in the exhaust stream. Appropriate manual or automatic protective features that prevent an uncontrolled release of radioactive material to the environment or workplace should be provided.

- Elevated confinement exhaust discharge locations can limit onsite doses and reduce offsite doses by enhancing atmospheric dispersion. An elevated stack should be used for confinement of exhaust discharge. Provisions should be made to provide an adequate ventilation exhaust discharge path in the event of stack failure. The stack should be located so that it cannot fall on the facility or an adjacent facility. Alternatively, the stack may be constructed to remain functional following accidents, including those caused by severe natural phenomena and man-made external events. Stack location and height should also consider intakes on the facility and adjacent facilities to preclude uptake.

- Guidance for air sampling locations is provided in ACGIH/ASHRAE criteria. Sample collecting devices should be located as close to the sampling probe as possible. Guidance for air cleaning device test port locations is provided by ASME N510, *Testing of Nuclear Air-Treatment Systems*.
- The number of air filtration stages required for any area of a facility should be determined based on the quantity and type of radioactive materials to be confined.
- Air filtration units should be installed as close as practical to the source of contaminants to minimize the contamination of ventilation system ductwork.
- Ducts should be sized for the transport velocities needed to convey particulate contaminants to filter media while minimizing the settling of those contaminants in the ducts.
- Ducts should be welded (transverse or longitudinal). Connections to equipment should be made using companion angle flanges.
- Air filtration units should be located and provided with appropriate radiation shielding to maintain occupational doses ALARA during operations and maintenance.
- Air filtration units should be designed to facilitate recovery of fissile material and other materials capable of sustaining a chain reaction.
- The cleanup system should have installed test and measuring devices (see ASME N510) and should facilitate monitoring operations, maintenance, and periodic inspection and testing during equipment operation or shutdown, as appropriate.
- Misters to cool inlet air and demisters to prevent soaking HEPA filters should be installed. Manual control of misters from the facility control center should be

considered. The inlet should have a temperature sensor with a readout on the facility control center monitor screen.

- Where spaces, such as a control room, are to be occupied during abnormal events, filtration systems on the air inlets should be considered to protect the occupants. Control rooms should also be protected from the entry of smoke or other toxic gases through ventilation air intakes. Compressed (bottled) air storage could be used to pressurize the control room if toxic gases are present at the air intake. Alternatively, two intakes, separately located, could lessen the likelihood of toxic gas intake.
- Either HEPA filtration or fail-safe backflow prevention for process area intake ventilation systems should be provided.
- Consideration should be given to specify cadmium-free HEPA filters to avoid generating mixed waste.
- Roughing filters or prefilters upstream of a HEPA filter should be considered to maximize the useful life of the HEPA filter and to reduce radioactive waste volume.
- When ducts with fire dampers penetrate the secondary confinement, boots may be needed for the clearance between the structure and the damper sleeve.

Hot cell exhaust systems considerations are as follows:

- Exhaust prefilters and HEPA filters should be installed to facilitate filter replacement and repair. Use of a bag-in/out type filter house can lessen personnel exposures.
- Standby filters should be considered to provide backup protection and facilitate primary filter replacement without shutting down the exhaust fans. Standby filters should be installed outside the cell and sealed in an acceptable enclosure for direct maintenance. Note: Air leakage through isolation valves/dampers should be evaluated to avoid the bypassing of filtration devices; the reduction of exhaust flow from recirculation through the standby filters; the exposure of personnel changing the isolated filter elements; and the premature loading of the standby filters.

- Exhaust systems should have monitors that provide an alarm if the concentration of radioactive material in the exhaust exceeds specified limits.
- If radioiodine may be present, consideration should be given to the installation of radioiodine-absorber units.

In facilities where plutonium or enriched uranium is processed, the following are additional considerations:

- Wherever possible, the designer should provide enclosures for confining process work on plutonium and enriched uranium. When these confinement enclosures are specified and designed, consideration should be given to whether room ventilation air for either a secondary or tertiary confinement can be recirculated. If a recirculation ventilation system is provided, the design should provide a suitable means for switching from recirculation to once-through ventilation.
- If advantageous to operations, maintenance, or emergency personnel, the ventilation system should provide for independent shutdown. Such a shutdown should be considered in light of its effect on the airflow in other interfacing ventilation systems. When a system is shut down, positive means of controlling backflow of air to uncontaminated spaces should be provided by positive shutoff dampers, blind flanges, or other devices.
- Equipment to continuously monitor oxygen levels should be provided for occupied working areas of facilities equipped with significant quantities of inert or oxygen-deficient process glovebox lines. Allowable leakage rates for ductwork systems should be taken into consideration.
- The supply of air to primary confinement, such as enclosures that confine the processing of plutonium and enriched uranium, should be filtered by HEPA filters at the ventilation inlets to the enclosures and area confinement barriers to prevent the transport of radioactive contamination in the event of a flow reversal.
- If room air is recirculated, the recirculation circuit should provide at least one stage of HEPA filtration. The design should include redundant filter banks and fans. If recirculation systems are used, contaminated process enclosure air should be prevented from exhausting into the working area rooms. Process

enclosure air (from hoods, gloveboxes, etc.) should be treated and exhausted without any potential for recirculation to occupied areas.

- The designer should specify and locate components in the exhaust systems to remove radioactive materials and noxious chemicals before the air is discharged to the environment. These components should be capable of handling combustion products safely. Exhaust system design should safely direct effluents through the appropriate ventilation ducts and prevent spread beyond the physical boundary of the ventilation system until treated.
- HEPA filters should be installed at the interface between the enclosures that confine the process and the exhaust ventilation system to minimize the contamination of exhaust ductwork. Prefilters should be installed ahead of HEPA filters to reduce HEPA filter loading. The filtration system should be designed to allow reliable in-place testing of the HEPA filter and to simplify filter replacement.
- Separate exhaust ventilation system ductwork and the initial two stages of filtration should be designed for exhaust air from enclosures that confine the process (e.g., gloveboxes). These systems should maintain a negative pressure inside the enclosure with respect to the operating area. These systems should be designed to remove moisture, heat, explosive and corrosive gases, and other contaminants. These systems should also be designed to automatically provide adequate inflow of air through a credible breach in the enclosure confinement.
- Enclosures that confine the process and are supplied with gases at positive pressure should have positive-acting pressure-relief valves that relieve the exhaust system to prevent over-pressurization of the process confinement system.
- The design of air cleaning systems for normal operations, anticipated operational occurrences, and accident conditions should consider use of the following equipment as appropriate:
    - prefilters,
    - scrubbers,
    - HEPA filters,
    - sand filters,
    - glass filters,

- radioiodine absorbers,
- condenser distribution baffles, and
- pressure and flow measurement devices.

Airborne contaminant cleaning systems should be designed for convenient maintenance and the ability to decontaminate and replace components in the supply, exhaust, and cleanup systems without exposing maintenance or service personnel to hazardous materials. Filtration systems should be designed so that a bank of filters can be completely isolated from the ventilation systems during filter element replacement.

Where the confinement system's ventilation ducting penetrates fire barriers, fire dampers should be appropriately used to maintain barrier integrity. However, the closure of such dampers should not compromise confinement system functions where the loss of confinement might pose a greater threat than the spread of fire. In such cases, alternative fire protection means (e.g., duct wrapping) should be substituted for fire barrier closure. In no case should a sprinkler system be considered a fire barrier substitute. (All penetrations of a fire barrier should be sealed, including conduit, cable trays, piping, and ductwork. In the selection of seals, requirements for pressure and water-tightness should be considered.)

1.2 CONFINEMENT SYSTEM DESIGN ASPECTS BY FACILITY TYPE

The preceding discussions of primary, secondary, and tertiary confinement generally apply to all nuclear facilities. The degree of applicability should be determined on a case-by-case basis. The following discussions provide some guidance on how to make these determinations as a function of facility type.

A description of the facility types is included in Section 2. "Containment" is addressed in Section 2.10.8.

1.2.1 **Plutonium Processing and Handling Facilities and Plutonium Storage Facilities (PSFs).** The degree of confinement required is generally based on the most restrictive hazards anticipated. Therefore, the type, quantity, and form (physical and chemical) of the materials to be stored should be considered. For materials in a form not readily dispersible, a single confinement barrier may be sufficient. However, for more readily dispersible materials, such as liquids and powders, and for materials with inherent dispersal mechanisms, such as pressurized cases and pyrophoric forms, multiple confinement barriers should be considered. U.S. Nuclear Regulatory Commission (NRC) Regulatory Guide (R.G.) 3.12, "*General Design Guide for Ventilation Systems of Plutonium Processing and Fuel Fabrication Plants*," provides useful guidance that should be considered.

Generally, for the most restrictive cases anticipated, three types of confinement systems should be considered:

- primary confinement—established by the cladding or the storage container (e.g., canning);
- secondary confinement—established by compartments with their ventilation systems; and
- tertiary or final confinement—established by the building structure and its ventilation system.

Exhaust ventilation systems are provided with HEPA filtration to minimize the release of plutonium and other hazardous material through the exhaust path. In addition, inlet ventilation to the secondary confinement systems should be provided with either HEPA filtration or fail-safe backflow prevention to minimize the release of plutonium and other hazardous materials through the inlet path.

Primary Confinement System. Cladding or storage containers typically provide primary confinement during normal operation and anticipated operational occurrences, and for accidents. Cladding or storage containers should provide corrosion-resistant confinement for fuel assemblies and to prevent an uncontrolled release of radioactive material. Special design features should be considered to provide safe introduction, removal, and handling of stored plutonium. These handling systems and equipment should be designed to protect against the dropping of storage containers, fuel assemblies, and other items onto the stored plutonium.

Secondary Confinement System. Compartments and their ventilation systems comprise the secondary confinement system. Secondary confinement barriers should have positive seals to prevent the migration of contamination. The use of positive seals should be considered for penetration of enclosures within the facility building to provide proper ventilation flow paths and to prevent the migration of contamination within the facility. Ductwork penetrations with fire dampers need clearance between the structure and the damper sleeve. Boots may be needed.

The need for special ventilation systems for confinement purposes should be based on results of the safety analysis. In general, each compartment should be supplied with ventilation air from the building ventilation system. Each compartment should also be provided with separate exhaust ventilation handled by a system with sufficient capacity to provide adequate ventilation flow in the event of a credible breach in the compartment confinement barrier. Pressure in the compartments should be negative with respect to the building ventilation system.

Tertiary Confinement System. The facility building and its ventilation system comprise the tertiary confinement system. Penetrations of the building confinement barriers should have positive seals to prevent the migration of contamination. Air locks or enclosed vestibules should also be provided for access through confinement barriers.

1.2.2 Unirradiated Enriched Uranium Storage Facilities. The following provisions are typical for an unirradiated enriched uranium storage facility (UEUSF) confinement system. The actual confinement system requirements for a specific UEUSF should be determined on a case-by-case basis.

The degree of confinement required is generally based on the most restrictive hazards anticipated. Therefore, the type, quantity, and form (physical and chemical) of the materials to be stored should be considered. For materials in a form not readily dispersible, a single confinement barrier may be sufficient. However, for more readily dispersible materials, such as liquids and powders, and for materials with inherent dispersal mechanisms, such as pressurized cases and pyrophoric forms, multiple confinement barriers should be considered.

Generally, for the most restrictive case anticipated, the use of three confinement systems should be considered. The primary confinement should be the unirradiated enriched uranium (UEU) cladding or the storage container (e.g., canning). Secondary confinement should be established by compartments with their ventilation systems. Tertiary or final confinement should be the building structure and its ventilation system.

Primary Confinement System. UEU cladding or storage containers typically provide primary confinement during normal operation, anticipated operational occurrences, and accidents. Cladding or storage containers are used to provide a corrosion-resistant confinement for the fuel assemblies and other UEU to prevent an uncontrolled release of radioactive material. Special design features should be considered to introduce, remove, and handle UEU safely. These handling systems and equipment should protect against the dropping of storage containers, UEU assemblies, and other items onto the stored UEU.

Secondary Confinement System. The compartments and their ventilation systems comprise the secondary confinement system. Penetrations of the secondary confinement barrier should have positive seals to prevent the migration of contamination. The use of positive seals should be considered for penetration of enclosures within the facility building to provide proper ventilation flow paths and to prevent the migration of contamination within the facility.

The need for special ventilation systems for confinement purposes should be determined based on the safety analysis. In general, each compartment should be supplied with ventilation air from the building ventilation system. Separate exhaust ventilation should be handled by a system with sufficient capacity to provide adequate ventilation flow in the event of a credible breach in the compartment confinement barrier. Pressure in the compartments should be negative with respect to the building ventilation system.

Tertiary Confinement System. The facility's building and ventilation system comprise the tertiary confinement system. Penetrations of the building confinement barriers should have positive seals to prevent the migration of contamination.

1.2.3 Uranium Processing and Handling Facilities. The following provisions are typical for a uranium processing and handling facility (UPHF) confinement system. The actual confinement system requirements for a specific UPHF should be determined on a case-by-case basis.

Generally, facilities that process and handle UEU have used two confinement systems. The primary confinement system encloses or confines the uranium materials being fabricated and the equipment used to process the uranium. The secondary confinement consists of the structures and associated ventilation systems that surround the operating areas that house the primary confinement system. The secondary confinement system barriers are those that separate the outside environment and free access areas, such as offices and lunch rooms, from potential contamination.

Primary Confinement System. The primary confinement system includes barriers, enclosures (including their associated ventilation or atmosphere control systems), and process piping and vessels. Its principal function is to prevent the release of hazardous substances into the operating areas. The following features should be considered in the design:

- Breaches of the primary confinement barrier (e.g., due to glove or seal failure) are acceptable if the off-gas treatment system is capable of maintaining an adequate inflow of air for the specified breach size and location. Some portions of the primary confinement may not form a complete physical enclosure. For these, primary confinement should be ensured by adequate airflow and appropriate process equipment design.
- If needed, conveyors should be used to interconnect glove holes or other primary confinement enclosures to minimize introduction and removal of materials from the system. The primary confinement system criteria should be applied to these interconnections.
- Special design features should be considered to safely introduce and remove materials from process confinements.
- Process vessels that could contain uranium should vent to the process off-gas system, which in turn should pass through pretreatment, if needed, and HEPA filtration.

Three types of metallurgical processes require special ventilation considerations:

- Processes that use volatile or easily entrained organic liquids should have a ventilation system that provides sufficient air movement around the process area to prevent exposure of personnel to the hazardous liquid or vapor. The design should incorporate roughing filters and/or other types of traps to remove entrained organic liquid droplets from the process off-gas before the off-gas enters the main ventilation. As a result, the ventilation ducts should not become coated with the organic materials, which would create a fire hazard.

- Processes that produce either finely divided particles of metal or small metal chips should have the same kind of front-end ventilation adaptations as for hazardous vapors and liquids to prevent metal accumulations in the off-gas ducting or in the final filtration train(s). Roughing filters or centrifugal separators may be sufficient to remove metal particles from the off-gas.
- Processes that use corrosive chemicals (e.g., acids, perchlorates) should use off-gas scrubbers to preclude damage to the exhaust air cleaning system (e.g., HEPA filtration train).

Metallurgical processing equipment should have dedicated ventilation systems that exhaust to a common, final filtration train. If airborne particle capture is required, a high linear velocity will be necessary to ventilate these process areas due to the greater densities of metal particles.

Ceramic processes involve oxide powder that is finely divided. The exposure of personnel to the powder inhalation hazard should be prevented. Processes that handle bulk ceramics such as pellets are not dust-free operations and thus, adequate ventilation should be provided.

Secondary Confinement System. The secondary confinement system generally consists of the confinement barriers and associated ventilation systems that surround or confine the operating areas that house the process system and its primary confinement.

The operating area compartments should have sensors that detect releases of hazardous materials from the primary confinement system and provide appropriate alarms. Commensurate with the potential hazard, the use of redundant sensors should be considered.

Penetrations of the operating area confinement barriers should be minimized. When practical, equipment components not functionally required to operate directly in the presence of radioactive materials should be located outside the operating area compartments. Penetrations of the secondary confinement should have positive seals to prevent the migration of contamination out of the operating area.

Each secondary confinement compartment should be supplied with ventilation air from the building ventilation system and should have exhaust ventilation with sufficient capacity to provide controlled ventilation flow as required in the event of a credible breach in the operating compartment confinement barrier. Pressure in the compartments should be negative with respect to the building ventilation system.

1.2.4 **Irradiated Fissile Material Storage Facilities.** The following provisions are typical for an irradiated fissile material storage facility (IFMSF) confinement system. The actual confinement system requirements for a specific IFMSF should be determined on a case-by-case basis.

In general, primary confinement is the irradiated fissile material (IFM) cladding or canning. Secondary confinement is established by the facility buildings that enclose the dry storage area and/or the storage pool and auxiliary systems.

Primary Confinement System. The IFM cladding or cans, as appropriate, provide primary confinement during normal and anticipated operational occurrences. The IFM cladding or canning are used to provide a corrosion-resistant confinement for the IFM material and to prevent an uncontrolled release of radioactive material.

Secondary Confinement System. The facility building and ventilation system make up the secondary confinement system.

Penetrations of the secondary confinement barrier should have positive seals to prevent the migration of contamination. The use of positive seals should be considered for penetration of enclosures within the facility building to provide proper ventilation flow paths and to prevent the uncontrolled migration of contamination.

Ventilation systems should include inlet air filtration (roughing filters) for the main storage building to prevent dust accumulation, thus reducing the load on other filters in the facility. Recirculated air in the main storage building should be filtered through a HEPA filter to reduce the build-up of radioactive material in the air. Areas with higher potential airborne radioactive contamination (e.g., pool water purification and waste treatment system areas) should use only once-through airflow. Supply air to these facilities should be drawn from the main storage building if such design is feasible. Exhaust air should be HEPAfiltered prior to release.

Radioiodine adsorber units, such as activated charcoal or silver zeolite, should be considered for installation in the exhaust ventilation system when radioiodine releases are possible.

Air should flow from areas of lower contamination to areas of higher contamination and areas of higher potential airborne contamination should be kept less than atmospheric pressure.

1.2.5 **Reprocessing Facilities.** The following provisions are typical for a reprocessing facility confinement system. Actual confinement system requirements for a specific reprocessing system should be determined on a case-by-case basis.

The degree of confinement required in various locations of the facility depends on the potential hazards associated with the process being carried out and is generally based on the most restrictive case anticipated. Design should consider the characteristics of the hazardous material involved, such as type, quantities, forms (physical and chemical), dispersibility, and energy available for dispersion.

In general, for the most restrictive case anticipated, the use of three confinement systems should be considered. In reprocessing facilities where processes require the use of corrosive or noxious materials, the process system should be totally enclosed and provided with its own ventilation system and off-gas cleanup system. In such cases, the process system should be treated as the primary confinement system. Secondary confinement should consist of the process cells and their ventilation system. Tertiary or final confinement should be the building structure and its ventilation system. In addition to these confinement systems, such features as change rooms and special access ways should be used to minimize the spread of contamination within the facility.

If heat transfer systems are used that provide circulation between radioactive and nonradioactive areas, barriers to release due to contamination of the heat transfer fluids should be considered. Typically, confinement would be provided through the use of intermediate heat exchangers and the use of a “closed-loop” system. A leak monitoring system should be considered.

Primary Confinement System. The primary confinement system consists of process systems equipment and the associated off-gas system. Process equipment failures should not cause failure of the secondary confinement system. Process equipment should operate under process conditions that prevent or minimize the probability of explosive chemical reactions.

Secondary Confinement System. The secondary confinement system consists of the process cell barriers and the ventilation systems associated with the cells. Design should consider the following features:

- Secondary confinement areas should be equipped with sensors that detect abnormal releases of hazardous material from the primary confinement boundary and provide appropriate alarms. Commensurate with the potential hazard, the use of redundant sensors should be considered.
- Penetrations of the secondary confinement should have positive seals to prevent the migration of contamination out of the secondary confinement area.
- The ventilation system should be designed to maintain a negative differential pressure during the removal of cell covers and for normal in-leakage at cell cover joints.
- Process cells should be supplied with ventilation air from the building ventilation system and with exhaust ventilation of sufficient capacity to provide controlled ventilation flow as required in the event of a credible breach in the secondary confinement barrier.
- Pressure in the compartments should be negative with respect to the building ventilation system.
- Special features (e.g., air locks, enclosed vestibules) should be considered for access through secondary and tertiary confinement barriers.

Tertiary Confinement System. The process building and associated ventilation system comprise the tertiary confinement system. Penetrations of the building confinement barriers should have positive seals to prevent the migration of contamination.

1.2.6 Uranium Conversion and Recovery Facilities (UCRFs). To the extent practical, the primary confinement system should be constructed of fire-resistant materials, and the process equipment and process being confined should be designed to prevent potential flammable or explosive conditions. Confinement enclosures for flammable metals should be designed with self-contained fire protection and extinguishing equipment; in some cases, inert atmospheres may be desirable within the enclosures.

Work that could subject personnel to possible inhalation exposures should be performed in process confinement enclosures. Gloveboxes should be the preferred enclosure, but are not always practical. Alternative systems may have to be considered.

When gloveboxes are used, their design and construction should allow replacement of parts and/or relocation of the box(es) within the facility or system(s) with a minimum of contamination or exposure.

To the extent practical, discrete processing steps should be performed in individual process confinements to reduce the amount of hazardous material that can be released by a single or local failure of the confinement system.

Process and auxiliary system differential pressure should be maintained to inhibit backflow of hazardous materials into auxiliary systems.

Generally, UCRFs have used two confinement systems. The primary confinement system encloses or confines the uranium materials being processed and the materials used to process the uranium. The secondary confinement consists of the structures and associated ventilation systems that surround the operating areas that house the primary confinement system. The operating areas include those areas that are not normally expected to become contaminated. The secondary confinement system barriers are those that separate the outside environment and free access areas, such as offices and lunch rooms, from potential contamination. The actual confinement system requirements for a specific UCRF should be determined on a case-by-case basis.

Primary Confinement System. The primary confinement system consists of barriers, enclosures (including their associated ventilation or atmosphere control systems), process piping and vessels, and so forth. Its principal function is to prevent the release of hazardous substances into the operating areas. The following considerations should be addressed in the design of primary confinement systems for UCRFs:

- Breaches of the primary confinement barrier (e.g., due to glove or seal failure) are acceptable if the off-gas treatment system is capable of maintaining an adequate inflow of air for the specified breach size and location. Some portions of the primary confinement may not form a complete physical enclosure. For these, primary confinement function should be ensured by adequate airflow and appropriate process equipment design.
- If needed, conveyors should be used to interconnect gloveboxes or other primary confinement enclosures to minimize introduction and removal of materials from the system. The primary confinement system criteria should be applied to these interconnections.
- Special design features should be considered to safely introduce and remove materials from process confinements.
- Process vessels that could contain uranium should be vented to the process off-gas system, which should route off-gas through pretreatment, if needed, and HEPA filtration. Typical pretreatment features include cyclone dust collection systems, different types of filters, cold traps, liquid condensers, solvent adsorption systems, and aqueous solution scrubbers. Nuclear criticality safety should be considered during the design of pretreatment and HEPA filtration systems.

Secondary Confinement System. The secondary confinement system generally consists of the confinement barriers and associated ventilation systems that surround or confine the operating areas that house the process system and its primary confinement. The following considerations should be addressed in the design of secondary confinement systems for UCRFs:

- Operating area compartments should be equipped with sensors to detect releases of hazardous materials from the primary confinement system and provide appropriate alarms. Commensurate with the potential hazard, the use of redundant sensors should be considered.
- Penetrations of the operating area confinement barriers should be minimized. When practical, equipment components not functionally required to operate directly in the presence of radioactive materials should be located outside the operating area compartments. Penetrations of the secondary confinement should have positive seals to prevent the migration of contamination out of the operating area.
- Each secondary confinement compartment should be supplied with ventilation air from the building ventilation system. Exhaust ventilation should be handled by a system with sufficient capacity to control ventilation flow as required in the event of a credible breach in the operating compartment confinement barrier. Pressure in the compartments should be negative with respect to the building ventilation system. The secondary confinement exhaust ventilation system should be equipped with HEPA filtration.

1.2.7 **Laboratory Facilities (Including Hot Laboratories).** The following provisions are typical for a laboratory facility confinement system. The actual confinement system requirements for a specific laboratory facility should be determined on a case-by-case basis.

If radioiodine may be present, consideration should be given to the installation of radioiodine absorber units in the exhaust ventilation/off-gas system to reduce the radioiodine concentration in the effluent.

Primary Confinement System.

- In hot laboratories, primary confinement usually consists of items such as a hot cell, glovebox, process piping, tank, fume hood, etc.; the volume enclosed is normally contaminated.

- The primary confinement volume and isolation systems, as appropriate, should be compartmentalized to isolate high-risk areas and to minimize the potential effects of accidents.
- The primary confinement system(s) should operate under process conditions that prevent or minimize the potential for explosive chemical reactions and should use ALARA design principles to minimize exposures.
- Design features for primary confinement for laboratory facilities and processes are facility-specific and should therefore incorporate the following features as appropriate:
  - Introduction and removal stations should provide for safe introduction and removal of material and maintenance equipment to and from the primary confinement.
  - Separate ventilation system or off-gas treatment system with appropriate air-cleaning capability (e.g., HEPA filtration, radioiodine absorbers, scrubbers) should be considered. The use of an inert gas atmosphere within the primary confinement is necessary when handling pyrophoric material. Special considerations should be given to systems that handle tritium (see Section 2.10, Tritium Facilities).
  - Ventilation and cleanup systems associated with the primary confinement system should not be shared with secondary and tertiary confinement systems.
  - Tanks within the primary confinement system should vent to the off-gas treatment system.
  - The operating pressure in the primary confinement system should be negative with respect to the secondary confinement.
- Gloveboxes should meet the following criteria:
  - Corrosive gases or particles from vats, scrubbers, and similar equipment should be neutralized prior to reaching HEPA off-gas filters.

  - A single filtered exhaust path should be acceptable when working with low-toxicity materials that do not require dilution or continuous cooling.
  - Exhaust flow rates (for air-ventilated gloveboxes) should confine in-box contaminants safely when an access port is opened or a glove ruptures.
  - If the glovebox is filled with an inert atmosphere, specific design criteria for emergencies (i.e., ruptured glove) should be incorporated on a case-by-case basis (e.g., pyrophoric materials).
- Hot cells should meet the following criteria:
  - Space and equipment should be provided as needed to support accountability, process monitoring, and material control requirements.
  - Exhaust prefilters and HEPA filters should be installed to facilitate filter replacement and repair.
  - Standby filters should be incorporated for backup protection during filter changes so that filters can be changed without shutting down the exhaust fans. Standby filters should be installed outside the cell and sealed in an acceptable enclosure for direct maintenance.
  - Exhaust systems should have alarms that will annunciate if the concentration of radioactive material in the exhaust exceeds the limits specified in the facility technical safety requirement.

Secondary Confinement System. The secondary confinement system usually consists of the facility operating compartments and associated ventilation systems. The secondary confinement houses the hot cells, gloveboxes, fume hoods, etc. The following design features should be incorporated into secondary confinement systems for laboratory facilities:

- design features to minimize the potential of the spread of contamination from within the laboratory facility operating areas to areas that are not normally contaminated;

- the use of a ventilation system separate from the primary confinement ventilation system with appropriate air-cleaning capability (e.g., HEPA filtration, radioiodine absorbers, scrubbers); and
- measures to provide negative operating pressure in the secondary confinement with respect to the tertiary confinement, especially where variable flow primary confinement exhaust systems (fume hoods) are utilized.

Tertiary Confinement System. The tertiary confinement system typically is the exterior laboratory building and its associated ventilation system. It is an area that is not contaminated and houses offices and other clean laboratory facilities. The following design features should be incorporated into tertiary confinement systems for laboratory facilities:

- the use of a ventilation system separate from the primary confinement ventilation system with appropriate air-cleaning capabilities (e.g., HEPA filtration, radioiodine absorbers, scrubbers) and
- measures to maintain operating pressure in the tertiary confinement negative with respect to the atmosphere.

The secondary and tertiary confinement ventilation systems may be shared if safety analysis indicates that this type of design is acceptable.

1.3 EFFLUENT CONTROL AND RADIATION PROTECTION

1.3.1 Introduction and Scope. This section addresses aspects of facility design specifically intended to provide for effluent control and radiation worker protection. Included are shielding, radiation monitoring systems, contamination control, and effluent monitoring. This treatment is not exhaustive; many lessons learned in design have been translated into regulations, Orders, and guidance documents, especially 10 CFR 835, *Occupational Radiation Protection;* DOE G 441.1-1C (CN1), *Radiation Protection Programs Guide for Use with Title 10, Code of Federal Regulations, Part 835, Occupational Radiation Protection*, DOE-STD-1098-2008 (CN1), *Radiological Control*; and DOE O 420.1C and its guidance documents.

Design of nuclear facilities should minimize personnel exposures to external and internal radiological hazards, provide adequate radiation monitoring and alarm systems, and provide adequate space for health physics activities. Primary radiation protection should be provided through the use of engineered controls (e.g., confinement, ventilation, remote handling, equipment layout, and shielding). Additional protection for workers should be provided through an effective radiation protection program that includes implementation of ALARA concepts.

Additional considerations for specific facility types are included in this handbook; see Section 2, Special Facilities and Activities.

1.3.2 **Shielding Design.** The shielding design basis should minimize exposure of an individual worker to ALARA levels. 10 CFR 835.1002 provides requirements in this area. In addition, appropriate shielding should be installed, if necessary, to minimize nonpenetrating external radiation exposures to the skin and lens of the eye of the worker. In most cases, the confinement barrier or process equipment provides this shielding. Shielding and other radiation protection measures should be provided for areas requiring intermittent access (e.g., to perform preventive maintenance, change components, and adjust systems and equipment). Straight-line penetration of shield walls should be avoided to prevent radiation streaming. American National Standard Institute/American Nuclear Society (ANSI/ANS-6.4-2006), *Nuclear Analysis and Design of Concrete Radiation Shielding for Nuclear Power Plants,* provides guidance regarding the design of concrete radiation shielding. ANS 6.4.2-2006, *Specification for Radiation Shielding Materials,* provides guidance regarding material specifications, where it provides a critical confinement or structural function. American Concrete Institute (ACI) 318M-11, *Building Code Requirements for Structural Concrete and Commentary,,* provides general guidance for the structural design of concrete shielding. Straight-line penetration of shield walls should be avoided to prevent radiation streaming.

Use of remote, shielded operations (i.e., through the use of handling equipment such as remote manipulators and lead glass windows) should be considered when exposures to extremities are anticipated to approach dose limits or where contaminated puncture wounds could occur.

NCRP Report No. 151, *Structural Shielding Design and Evaluation for Megavoltage X- and Gamma-Ray Radiotherapy Facilities,* provides guidance regarding shielding design and evaluation for mega voltage accelerator facilities.

1.3.3 **Airborne Radiation Control.** Established airborne concentration limits for normal operating conditions should not be exceeded in occupied operating areas. 10 CFR 835.1002(c) provides requirements for limiting concentrations. ALARA principles should be used when designing confinement and ventilation systems to limit airborne contamination levels. Respirators should not be required during normal operations. Engineered controls and features should minimize potential inhalation of radioactive and other hazardous materials under all conditions. ASME N509, *Nuclear Power Plant Air-Cleaning Units and Components,* and ASME N510, *Testing of Nuclear Air-Treatment Systems,* provide guidance for the design and testing of nuclear facility HVAC systems.

Monitoring systems should be calibrated at least annually using appropriate national standards. Radiation monitoring, alarm, and warning systems, which are required to function during a loss of normal power, should be provided with an emergency uninterruptible power supply (UPS) (internal or external on-line) unless it can be demonstrated that these systems can tolerate a temporary loss of function without losing needed data and that they are provided with standby or emergency (switched) power. Determination of the power supply type and quality should be based on the safety classification of the monitoring system or device. The sampling motivation (vacuum) type and quality should also be based on the safety classification.

Air monitoring and warning systems should be installed in work areas where hazardous materials are stored or handled or where hazardous airborne particles or vapors may be present. Air sampling heads should be located to provide a representative sample of potential airborne radioactive or hazardous materials being breathed. ANSI/HPS N13.56-2012, *Sampling and Monitoring Releases of Airborne Radioactivity in the Workplace* provides guidance for the design of air monitoring systems.

Operation and maintenance of special facilities may lead to situations (e.g., accidents, special maintenance, and spill recovery) where air-supplied respiratory protection is required. ANSI Z88.2, *Respiratory Protection,* and 29 CFR 1910.134, *Occupational Safety and Health Standards,* provide guidance for the design of breathing air supply systems.

1.3.4 **Contamination Control.** Use of devices to warn personnel of possible radioactive or other hazardous contamination should be evaluated and provided in accordance with the evaluation. Personnel monitoring devices, such as hand and foot counters, should be provided in the vicinity of workstations. Installed monitors (supplemented with personal monitoring methods) should be used to monitor personnel exiting an operating area. Continuous air monitors (CAMs) should be used to detect and alarm at prescribed airborne radioactivity levels. American National Standard N13.49-2001 (R2011), *Performance and Documentation of Radiological Surveys*, provides both specific and general guidance for facilities using radioactive material or machines producing radiation fields.

Facility design should locate personnel decontamination facilities close to areas that represent potential contamination sources. Decontamination facilities should be designed to minimize the inadvertent spread of contamination during personnel decontamination activities.

Change rooms should be provided for changing into and from protective clothing. These areas should be separate for male and female workers and be located adjacent to shower facilities. Change rooms should be designed to segregate clean clothing (e.g., personal clothing) and protective clothing. Storage of contaminated protective clothing should be controlled so that contamination does not spread. Change room exhaust air should be HEPA filtered if dispersible radionuclides are handled in the process areas it serves.

1.3.5 **Radiation Monitoring.** In the presence of ionizing radiation (due to process material, equipment, or operations), an area radiation monitoring and alarm system is used to alert personnel of unexpected increases in ionizing radiation levels. Warning and alarm systems should be designed, installed, and tested to confirm that they can be heard in the ambient conditions of the area in which they are placed. If a criticality excursion could potentially occur, including a potential for personnel exposures, nuclear accident dosimeters should be installed. ANSI/ANS 8.3-1997, Reaffirmed 2012, *Criticality Accident Alarm System,* provides guidance for criticality accident alarms and the design of evacuation alarm systems.

In addition to a local station alarm, radiation monitoring systems (i.e., criticality alarms, CAMs, alarms associated with stack monitoring systems) should have central (i.e., control room or radiation monitoring office) readout and alarm panels that are accessible after an accident so that internal conditions can be evaluated.

1.3.6 **Airborne Effluents.** For nonradioactive hazardous gaseous or airborne effluents, the point of release is the point at which the effluent exits the stack, vent, or other release points.

Exhaust ducts (or stacks) that may contain radioactive airborne effluents should be provided with effluent monitoring systems. The monitoring capability should cover the range from normal effluent concentrations to the maximum concentration expected from a credible accidental release. For exhaust outlets that may contain plutonium, uranium, enriched uranium, tritium, transuranics or fission products, and other radioisotopes above ambient levels, two independent monitoring systems should be considered.

Backup capability for monitoring systems should be considered in the design of each system (e.g., redundant detectors, additional sample line ports, additional sampler trains, etc.). Continuous stack sampling and continuous radiation detection should also be considered. ANSI N13.1-2011, *Sampling and Monitoring Releases of Airborne Radioactive Substances from the Stacks and Ducts of Nuclear Facilities* provides guidance on designing sampling systems that provide accurate, representative sampling of effluent streams.

Airborne effluents from confinement areas should be exhausted through a ventilation system designed to remove hazardous particulate material, vapors, or gases. ALARA should be implemented to minimize effluent concentrations and quantities released for hazardous materials. Isokinetic sampling should be provided for effluent streams that are expected to contain particulate radionuclides. After HEPA filter installations, anisokinetic sampling may be satisfactory, due to the small particle sizes in the effluent.

Consideration should be given to including process confinement off-gas treatment systems to preclude the accumulation of potentially flammable quantities of hydrogen generated by radiolysis or chemical reactions within process equipment. Vent streams with the potential of containing significant quantities of radioactive material should be processed by an off-gas cleanup system before being exhausted to the environment.

The following additional features should be considered in off-gas systems:

- providing vents from liquid components with traps and drains to prevent inadvertent flooding of off-gas systems;
- neutralizing corrosive gases and particles from vats, scrubbers, and similar equipment in gloveboxes before they reach the HEPA off-gas filters;
- equipping vent streams containing UF6 with chemical traps to remove radionuclides from the gases before they are vented to the atmosphere. The following vents are typically equipped with traps:
  - purge cascade,
  - cold recovery,
  - buffer seal exhaust stations, and
  - wet-air evaluation stations.

Consideration should also be given to the need for equipment to provide meteorological parameters (e.g., wind speed, wind direction, humidity data, and wind direction frequencies for heights related to the estimated heights at which stack effluents and cooling tower moisture will be dispersed). As necessary, installation of special equipment for stack effluent dispersal and tracking should be considered.

1.3.7 **Effluent Control.** Generally, there will be statutory limits on facility effluents and concentrations at the point of discharge and/or the site boundary. These statutory requirements should be identified and their requirements implemented in design. Consideration should also be given to concentrations at neighboring facilities, and even to operations areas of the facility outside the building, especially for chemical releases. The design of monitoring and control systems that reduce effluents released to the environment to ALARA levels should emphasize the use of features that employ the best technology economically available at the time of design. Confinement systems should minimize the release of radioactive and other hazardous materials in facility effluents during normal operation and anticipated operational occurrences.

1.3.8 **Effluent Monitoring.** Design for effluent monitoring should consider the following:

- Sampling and monitoring systems provide adequate and accurate measurements under normal operations, anticipated operational occurrences, and accident conditions. Monitoring systems should be calibrated at least annually according to appropriate national standards.
- Exhaust outlets that may contain radioisotopes other than ambient levels of those naturally occurring in the environment should be provided with monitoring systems. As necessary, special equipment for stack effluent dispersal and tracking should be considered for installation. Such monitoring provides data useful for dispersion analysis of effluent materials.
- Stack monitoring systems should have central (i.e., control room or radiation monitoring office) readout and alarm panels that are accessible after an accident to evaluate internal conditions. Such data are useful for designing the most appropriate and efficient response to a release-related incident.
- Radiation monitoring, alarm, and warning systems required to function during a loss of normal power should be provided with an emergency UPS (internal or external on-line). However, if it is demonstrated that these systems can tolerate a temporary loss of function without losing needed data and these systems are provided with standby or emergency (switched) power, the emergency UPS is not necessary. Determination of the power supply type and quality, including availability during and after events, should be based on the safety classification of the monitoring system or device. Emergency backup power systems are critical to the operation of monitoring, alarm, and warning systems in the case of a simultaneous power failure and radioactive release.

ADDITIONAL REFERENCES

DOE Orders and Standards

DOE-STD-1020-2012 *Natural Phenomena Hazards Analysis and Design Criteria for DOE Facilities*

DOE STD-3014-2006 *Accident Analysis for Aircraft Crash into Hazardous Facilities*

DOE-STD-3025-2007 *Quality Assurance Inspection and Testing of HEPA Filters*

Other Government Documents

NRC R.G. 3.54 *Spent Fuel Heat Generation in an Independent Spent Fuel Storage Installation*

NRC R.G. 8.8 *Information Relevant to Ensuring that Occupational Radiation Exposures at Nuclear Power Stations Will Be as Low as Is Reasonably Achievable*

Non-Government Documents

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