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Radiological Design Guide

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RADIOLOGICAL DESIGN GUIDE

1.0 INTRODUCTION

1.1 PURPOSE

The purpose of this design guide is to provide radiological safety requirements, standards, and information necessary for designing facilities that will operate without unacceptable risk to personnel, the public, or the environment as required by the U.S. Department of Energy (DOE).

1.2 SCOPE

This design guide, together with WHC-CM-4-29, Nuclear Criticality Safety, WHC-CM-4-46, Nonreactor Facility Safety Analysis, and WHC-CM-7-5, Environmental Compliance, covers the radiation safety design requirements at Westinghouse Hanford Company (WHC).

This design guide applies to the design of all new facilities. The WHC organization with line responsibility for design shall determine to what extent this design guide shall apply to the modifications to existing facilities. In making this determination, consideration shall include a cost versus benefit study. Specifically, facilities that store, handle, or process radioactive materials will be covered. This design guide replaces WHC-CM-4-9 and is designated a living document.

This design guide is intended for design purposes only. Design criteria are different from operational criteria and often more stringent. Criteria that might be acceptable for operations might not be adequate for design.

1.3 DEFINITIONS

Different types of requirements are addressed in this guide and are denoted by specific verbs. Shall indicates a mandatory requirement necessary to comply with DOE and DOE-directed State, Federal, or local requirements. Shall also refers to generally accepted good practice, especially as documented in national and international standards. Should and may indicate guidelines or recommendations. Exceptions are expected to be made through the application of sound engineering judgement.

1.4 RESPONSIBILITIES

Project/facility organizations are responsible for ensuring that the recommendations of this design guide are incorporated into the design of new and modified WHC facilities in accordance with WHC-CM-1-3, Management Requirements and Procedures, MRP 5.43, "Impact Levels," WHC-CM-4-2, Quality Assurance, and WHC-CM-6-1, Standard Engineering Practices.

Emergency, Safety, and Quality Assurance have the responsibility of providing independent review of design documentation to ensure that the recommendations of this design guide are incorporated into the design of new and modified WHC facilities.

1.5 OPTIMIZATION

Reduction of radiation exposure to as low as reasonably achievable (ALARA) depends on the interpretation of "reasonably achievable." An optimization process was introduced by the International Commission on Radiological Protection (ICRP) to assist in applying and interpreting the ALARA principle. To accomplish this, the cost benefit analysis is performed utilizing WHC-SA-1533-FP, Cost Benefit Analysis at WHC. Decisions on whether or not to include dose reduction measures as design features when costs exceed this value should be evaluated on a case-by-case basis. Examples of application of the optimization concept can be found in ICRP 37, Cost-Benefit Analysis in the Optimization of Radiation Protection, and U.S. Nuclear Regulatory Commission Guide NUREG/CR-3254, Licensee Programs for Maintaining Occupational Exposure to Radiation As Low As Reasonably Achievable.

1.6 RELIABILITY AND HUMAN FACTORS

Generally, radiological designs should provide highly reliable equipment because of the risk equipment failure would impose on exposure or release of radioactive material. Additional incentives for high reliability are that failed equipment is difficult to diagnose, repair, and/or dispose of.

Human factors engineering is crucial in the design of radiological facilities because radiological conditions often impede or restrict the human faculties of radiation workers (masks, protective clothing, intricate procedures, etc.). A guide to Human Factors Engineering can be found in Appendix A.

1.7 SAFETY ANALYSES

The WHC policies require that facilities containing radioactive or fissionable materials be managed in a manner which ensures no undue risk of accidents that could affect the health and/or safety of employees, visitors, or members of the general public, and which protects the facilities and the environment from unacceptable risks. Safety analysis is covered in WHC-CM-4-46, Nonreactor Safety Analysis.

1.8 OPERATIONS AND MAINTENANCE

In the designing of facilities, all aspects of operation and maintenance should be considered. This includes accessibility, dismantling, replacement, repair, preventive maintenance, inspection, personnel safety, and daily operations. Facility planning and design documentation should be reviewed by those persons who will be responsible for operating and maintaining the completed facilities. Unusual Problem Reports, Radiation Problem Reports, and Nonconformance Reports should be used to identify and avoid shortcomings of past designs.

Equipment that requires periodic inspection, maintenance, and/or testing should be located in areas with the lowest possible radiation and contamination levels. Equipment that is expected to be contaminated during operation should have provisions for both inplace maintenance and removal to an area with low dose rates for maintenance. An alternative is to use less expensive, throw-away equipment. Maintenance areas for repair of contaminated equipment shall include provisions for confinement of radioactive materials and contamination.

1.9 EMERGENCY PREPAREDNESS

The need for an emergency control station shall be determined for each facility in the initial design effort to provide "a location within or near a designated critical facility or plant area for the purpose of maintaining control, orderly shutdown, and/or surveillance of operations and equipment during an emergency," (DOE Order 5500.2).

Facilities shall be designed to facilitate the arrival and entry of emergency personnel and equipment in the event of an emergency and to allow access for repair/corrective action personnel.

Equipment shall be available to allow an early an reliable determination of the seriousness of an accident. Installed online equipment shall be protected to the extent necessary to ensure reliability under accident conditions. To further enhance equipment reliability, the emergency equipment should be the same equipment used during normal operations (DOE Order 5500.2).

The design effort shall identify the emergency power requirements that need to be satisfied and the means to provide it.

Emergency radiological equipment shall be installed or located in areas that allow periodic inspection, testing, and maintenance.

1.10 DECONTAMINATION AND DECOMMISSIONING

Decommissioning requirements should be considered in the design of a facility. Section 3.0 contains design criteria pertinent to the decontamination and decommissioning of nuclear facilities.

1.11 LICENSES, PERMITS, AND NOTIFICATIONS

Construction of new or modifications to existing facilities may require State of Washington licenses, permits, or approval. Refer to WHC-CM-7-5, Environmental Compliance, for requirements applicable to specific projects.

2.0 Facility Layout

2.1 Layout

Facility layout is an important factor for controlling exposure of individuals to radiation. A primary function of facility layout design is to control the traffic flow of personnel and material within the facility. Proper layout separates areas with high personnel occupancy from areas of high radiation.

Proper facility design regulates personnel access to sources of ionizing radiation. The regulation is achieved by designating two types of areas controlled and uncontrolled and restricting access to the controlled areas.

These guidelines are provided for design of new facilities and modifications to existing facilities. Dose and dose rate limits contained in this section are for design purposes and are not necessarily related to dose and dose rate definitions for existing areas as contained in DOE Orders and other WHC manuals.

2.2 UNCONTROLLED AREA (See Glossary)

For the purpose of radiation protection, access to uncontrolled areas is not restricted. Access may be restricted to meet other requirements. Examples of uncontrolled areas include offices, conference rooms, reception areas, lunchrooms, and laboratories where radioactive materials are not present. The following are design criteria:

1. In uncontrolled areas, no shielding is required to reduce the dose rate to less than 0.001 mSv per hour or 0.04 mSv per week and no special ventilation or containment requirements are necessary to maintain exposure to radioactive materials to background levels. Note that 1 mSv = 100 mrem.

2. Uncontrolled areas shall be designed to provide an additional level of confinement during design basis accident (DBA) conditions but shall not be considered a confinement barrier for less serious accidents.

3. Radioactive lines shall not be routed through uncontrolled areas.

2.3 CONTROLLED AREA

Design Criteria:

1. In controlled areas, shielding shall be provided to reduce the dose rate to personnel in accordance with Section 8.0.

2. The concentration of airborne radioactive materials in areas normally accessible to personnel shall be maintained ALARA. The design objective is essentially zero internal exposure of plant personnel.

3. Each controlled area should have a minimum of access (entrance and exit) point for personnel during normal operation. Access points should be accessible through change rooms.

4. Additional entrance and exit points shall be available as required for emergencies by Industrial Safety.

5. Ventilation air flows shall be in the direction of uncontrolled areas to controlled areas. Airlocks should be considered when pressure differentials between uncontrolled and controlled areas result in unacceptably high airflow rates, or when additional barriers to the spread of contamination are required.

6. The secondary confinement barriers should limit the amount of radioactive materials that might be released to uncontrolled areas within the facility and to the environment. These barriers consist of structural walls and ventilation systems.

7. Operations that are sensitive to radiation levels, or fluctuations in radiation levels, should be isolated and shielded (e.g., radioactive sample counting, photographic operations).

8. Mechanical equipment such as pumps and valves that are a potential source of radioactive contamination should be located in the controlled areas.

2.4 RADIATION AREA

Design Criteria:

1. In radiation areas, the facility design goal should be to limit radiation exposures to personnel to 0.5 rem/yr (see Section 8.0 for further information).

2. Fixed radiation monitoring systems with local and remote readouts should be provided for radiation areas when they are required by Section 553 of the HSRCM-1, Hanford Site Radiological Control Manual. (see Section 10.0 for further information).

3. The primary confinement barrier for radiation areas should consist of structural envelopes and ventilation systems. The primary and secondary confinement barriers should be designed to remain functional during a DBA.

4. Engineering shall be used for the containment of radioactive material for operations that require handling of dispersible radioactive materials outdoors should not be permitted.

5. Doors providing direct access to the outdoors from radiation areas are permissible provided they are used only as emergency exits or for nonroutine operations. These doors should have air-tight seals and audible alarms that signal an open door. Consideration should be given to airlocks on emergency exits from high contamination areas.

2.5 HIGH RADIATION AREA

Access to high radiation areas shall be controlled during normal operations by one or more of the following features:

1. A control device that, before entry into the area, causes the level of radiation to be reduced below that level at which an individual might receive a dose equivalent of 1 mSv in one hour at 30 cm from the radiation source or from any surface that the radiation penetrates.

2. A control device that energizes a conspicuous visible or audible alarm signal so that the individual entering the high radiation area and/or the supervisor of the activity are made aware of the entry.

3. Entryways that are locked except during periods when access to the area is required.

4. One-way doors (with crash bars) shall be used to prevent personnel from being locked in high radiation areas.

5. A device that functions automatically to prevent the use or operation of the radiation source or field while personnel are in the area.

2.6 CORRIDORS AND NORMAL TRAFFIC PATTERNS

1. The normal personnel traffic flow to controlled areas should be routed through uncontrolled areas and past the radiation control station prior to personnel entering the change room.

2. Areas with the potential for either contamination or radiation exposure should be located away from the normal personnel traffic flow.

3. Corridors should be designed to accommodate passage of personnel, material, and equipment and to provide ready access to various areas within the facility.

4. Airlocks should be provided at passages through contamination control barriers.

5. Airlock doors should be alarmed so that personnel are alerted if more than on door is opened at a time.

6. Space for stepoff pads, clothing and waste containers, and personel contamination monitors and survey equipment shall be provided at the exit from controlled areas that are potentially contaminated and between high and low level contamination areas (see Section 3.0 for further information).

3.0 CONTAMINATION CONTROL

3.1 INTRODUCTION

This section provides criteria and guidance to ensure that radioactive contamination control measures are incorporated during facility design as required by the DOE. Contamination control is an important part of ALARA. DOE Order 6430.1A, General Design Criteria, requires that the design of facilities incorporate measures to limit the spread of contamination and simplify future decontamination.

This section provides detailed criteria and guidance in order that DOE contamination control requirements are incorporated into the design of facilities.

3.2 GENERAL

1. The facility shall be designed so that contamination control is maintained even if equipment or operating procedures fail.

2. Radioactive contamination shall be confined as close as practical to the source (see Sections 4.0, 6.0, and 7.0 for methods of accomplishment).

3. Primary means for ensuring contamination control shall be through physical measures, e.g., ventilation, encapsulation, fume hoods, enclosures, gloveboxes, hot cells, etc.

4. Features that minimize the buildup of contamination and which facilitate clean up shall be implemented in facility designs.

5. Design of the areas in a facility that may become contaminated with radioactive or other hazardous materials under normal or abnormal operating conditions shall incorporate measures to simplify future decontamination.

3.3 ARCHITECTURAL AND STRUCTURAL

3.3.1 LAYOUT

1. To the degree practical, like-numbered ventilation confinement zones should be grouped together.

2. Laboratories, offices, and other spaces shall be arranged to minimize traffic through Secondary confinement.

3. There shall be no traffic through primary confinement areas.

4. Change rooms shall be provided when operating and/or maintaining the facility requires use of protective clothing (DOE 6430.1A).

5. Change rooms should be divided into controlled and uncontrolled portions.

3.3.2 EXIT POINTS

1. Space for stepoff pads, used protective clothing and waste containers, and radiation monitoring survey equipment shall be provided for personnel and equipment at the boundary of the surface contamination area and for leaving contaminated areas.

    - Separate personnel change rooms shall be provided for men and women for them to change into modity clothing.

    - Lockers and showers should be provided for the anticipated number of radiation workers in the facility.

    - Restroom facilities should be installed in the uncontrolled portion of the chance rooms.

2. The uncontrolled portion of a change room should have a well-defined area for storing and dispensing of clean protective clothing and personal protection equipment (PPE). Temporary storage of potentially contaminated clothing shall be provided in the controlled portion of the change room.

3. Change room ventilation system should be designed to cause the air to flow from the uncontrolled to the controlled portion of the room.

3.3.3 OPERATIONAL HEALTH PHYSICS LABORATORY OFFICE

1. Each facility designed to handle radioactive material should provide the space and furniture for at least one Radiation Control Technologist.

2. For facilities with more than 30 radiation workers, the operational health physics laboratory office shall provide the space and furniture to accommodate additional personnel.

3. Each laboratory office should include, in addition to standard office requirements, a minimum of 6 lineal feet of laboratory bench space, 12 lineal feet of open shelving, and 1 electrical outlet for every 2 feet of bench space. Space should also be provided for at least 2 supply and equipment cabinets (36" wide, 18" deep, by 72" high). Two lineal feet of laboratory bench space and 4 lineal feet of open shelving should be added to the above requirements for each additional technologist provided for.

3.3.4 EQUIPMENT DECONTAMINATION AND MAINTENANCE

1. A decontamination and maintenance facility should be provided for any facility designed to handle radioactive material in dispersible form.

2. The design of a decontamination and maintenance facility should take into account the following:

    - Type and quantity of radioactive material
    - Quantity of tools and equipment to be processed
    - Remote visual inspection of radioactive components
    - Handling and transfer of components including remote handling

- Physical separation of activities such as decontamination, remote maintenance, contact maintenance, and storage.

3.3.5 PERSONNEL DECONTAMINATION

1. A personnel decontamination room shall be provided for any facility having potentially contaminated areas. The personnel decontamination room should be located near the exit point from the contaminated area.

2. As a minimum, the decontamination room shall be provided with a telephone, a work bench, an examination chair, a sink and shower connected to a radioactive liquid waste system or to a monitored sewer system, and a storage cabinet for decontamination supplies.

3. The decontamination room should provide the capability to decontaminate men and women simultaneously. The use of permanently installed partitions or curtains should be considered for this purpose.

3.3.6 INTERIOR WALLS, CEILINGS, PARTITIONS, AND FLOORS

1. The surfaces of interior walls, ceilings, partitions, and floors in confinement areas shall be finished with washable or stripable coverings. To the extent practicable, surfaces in primary confinement should be stainless steel. Where paints must be used in primary confinement, they shall comply with American National Standards Institute (ANSI) Standard N512, Protective Coatings (Paints) for the Nuclear Industry. Yellow paint shall not be specified for use in primary and secondary confinement.

2. All penetrations and joints between primary and secondary confinement should have positive seals.

3. The surfaces of interior walls, ceilings, partitions, and floors in primary and secondary confinement shall be designed to minimize buildup of contamination and to facilitate decontamination. This should be accomplished by evaluating and incorporating the following features:

    - All cracks, crevices, and joints should be caulked and finished smooth

    - Sharp inside corners should be avoided in primary confinement.

4. Sheet metal panel walls, concrete blocks, and other porous construction materials should be avoided in walls defining boundaries between ventilation confinement zones where pressure control is required.

3.3.7 LABORATORY

For contamination control purpose in secondary confinement, the following features should be incorporated to the extent practicable:

1. Minimize the amount of furniture and equipment required to support operations.

2. Incorporate smooth, crack-free surfaces, rounded corners and junctions, and enclosed pipe and wiring.

3. Avoid the use of porous construction materials at boundaries between secondary confinement and adjoining zones where pressure control may be required.

3.4 MECHANICAL

3.4.1 VENTILATION

Ventilation shall be in accordance with Section 4.0, "Ventilation."

3.4.2 PROCESS PIPING, VESSELS, AND EQUIPMENT

To the extent practical, piping, vessels, and equipment processing contaminated fluid should incorporate the following features:

1. Interior surfaces should be smooth, nonporous, and free of cracks, crevices, and sharp corners.

2. Piping and vessels should be free from dead spaces and stagnant legs.

3. Materials should be compatible with the fluids being processed, transported, or stored.

4. Cleanup systems should be provided to remove solids.

5. Connections should be located above the pipe centerline.

6. Pipes and vessels should be sloped to be self draining.

7. Features to permit recirculation or flushing of fluids should be provided.

8. Redundant components and capability to isolate components should be considered.

9. Long-life components should be provided.

10. Pipe fittings should be limited to the minimum number compatible with operation and maintenance activities.

11. Pipe length should be limited to that compatible with operation and maintenance activities.

12. Floors should be sloped to local drains or sumps.

13. Process pipes and vessels which handle contaminated fluids should be separated from those which do not.

14. Valves should be full port whose bore matches the internal diameter of connected lines.

15. Cavities in valves should be avoided.

16. Large radius pipe bends, i.e., at least five pipe diameters, should be used.

17. Butt welds should be used.

18. The use of tees should be minimized. When used, orient the branch horizontally or preferably above the run (straight through portion of tee). Flow should be through the run of the tee.

19. Provisions to agitate process and storage vessels should be provided.

20. Materials that are resistant to radiation damage should be used in high radiation areas.

21. Live-loaded valve packings or bellow seals should be used.

22. Enclosed pumps should be used.

23. There should be no cross connections between contaminated and noncontaminated systems. If cross connections are necessary, an air gap should be used to prevent backflow of contaminated liquids into the noncontaminated system.

24. Every pipe entering or exiting a process cell and/or contamination area should be equipped with a block (isolation) valve.

25. Teflon, or other materials subject to radiation damage at relatively low exposure, should not be used for flange gasket material in contaminated process piping systems or for a component part of any valve or other piece of equipment subject to radiation.

26. Pipe sleeves should generally be provided when piping passes through masonry or concrete walls, floors, and roofs (except shielding walls). Sleeves should be sloped to drain toward the controlled area. The space between the pipe and the sleeve should be packed and sealed with a suitable caulking compound.

27. In general, contaminated piping should not be located underground. Shielding requirements may necessitate burial of piping to carry contaminated liquids. If underground piping is required, it shall be encased. Sample drains should be installed in the encasing pipe to monitor for leaks in the original pipe. See Section 11.0 for additional requirements applicable to contaminated piping.

28. Flanges should be used at equipment nozzles only when necessary for servicing.

29. Eccentric reducers should be used in horizontal pipe runs. Orientation should be such that the straight-through side is down.

3.4.3 MAINTENANCE

To the extent practicable, piping, vessels, and equipment processing contaminated fluids should incorporate the following features:

1. Adequate space to permit maintenance, including the removal and replacement of components, should be provided.

2. Equipment that requires frequent maintenance should be located for easy access.

3. Provisions should be made for the quick and easy removal of shielding and insulation that cover areas where maintenance or inspection is necessary. Equipment shall be designed to permit visual inspection wherever possible.

4. The capability to drain fluids to the radioactive liquid waste system prior to disassembly of equipment should be provided.

5. The capability to isolate and flush components should be provided.

6. Quick disconnects should be provided where appropriate.

3.4.4 DECONTAMINATION AND DECOMMISSIONING

The facility shall be designed to facilitate decontamination for reuse and for ultimate decommissioning. From the contamination control aspect, this can be accomplished by incorporating the design criteria contained in this design guide.

4.0 Ventilation

4.1 Objective

This section provides the requirements and guidelines for the design and construction of ventilation systems to confine airborne radioactive materials within designated areas of the building, remain functional during all operational modes, and fail safely during credible accident conditions. The inclusion of the requirements of this section together with good engineering design practices should provide an adequate safety envelope.

4.2 General Ventilation Design Criteria

1. These criteria provide a design guide for new facilities, and also serve as guidelines for line item and general plant project modifications to existing facilities involving portions of a building.

2. The ventilation system shall be designed and constructed in accordance with DOE 6430.1A, General Design Criteria, to confine airborne radioactive materials within the areas of the building where they originated.

3. The ventilation system shall be designed to clean radioactive particles and vapor from normally or accidentally contaminated air effluent streams before release to the environment to levels that are ALARA.

4. The ventilation system is a safety feature of a nuclear or radioactive material facility. As such, it shall be designed to complement the building layout and shall remain functional during all operational modes and fail safely during credible accident conditions where shutdown of operations is acceptable.

4.3 Ventilation Confinement Zones

To optimize the confinement properties of the ventilation system, three confinement zones shall be planned. Secondary zone subdivisions may be required. Confinement zones are defined as follows:

4.3.1 Primary Confinement Zone

Confinement features of the primary confinement zone shall prevent the spread of radioactive material to adjacent zones under both normal and abnormal operating conditions, up to and including the DBA for the facility.

Some examples of primary confinement are the interior of a hot cell, glovebox, or other confinement device used to confine radioactive material, including the exhaust ductwork.

4.3.2 Secondary Confinement Zone

The secondary confinement zones are ordinarily free of contamination but have a potential for being contaminated.

Some examples are rooms containing gloveboxes, hot cell service or maintenance areas, hot cell operating areas, general chemical laboratories, maintenance and other general working areas that are usually uncontaminated but which are subject to low levels of radioactive material contamination, and areas such as hallways and change rooms.

4.3.3 Tertiary Confinement Zone

The walls, floor, roof, and associated exhaust systems of the facility shall prevent a release of radioactive material from the building under normal operation and DBA. These areas shall be separated from secondary confinement by physical barriers and enclosed vestibules.

This includes all areas within the building that are not classified as part of the primary or secondary confinement, such as offices, lunch rooms, and other support areas that are intended to remain free of contamination at all times.

4.4 Airflow Patterns and Pressure Differentials Requirements

4.4.1 Building Airflow Pattern

The ventilation system shall be designed to produce an airflow pattern from the environment into the building. The airflow patterns within secondary confinement shall be designed to minimize eddies and areas of stagnation, restrict the spread of contamination, and provide a flow of air in occupied areas to direct material away from the breathing zone of personnel.

4.4.2 Building Pressure Gradients

Within the building, the ventilation system shall establish and maintain a negative pressure gradient from uncontaminated areas to areas of successively higher potential for contamination.

Table 4-1 lists the acceptable negative pressure differentials. A pressure gradient between areas within secondary confinement may be required; a 0.05 inches water differential pressure between such areas is generally adequate.

4.4.3 Air Changes

The volumetric airflow rate in secondary confinement housing, primary confinement, or access ways shall provide between four and eight air changes per hour.

Sufficient ventilation system capacity shall be available to immediately cause a velocity of 100 feet per minute (fpm) into a breached glove port or other opening(s) that may occur in confinement or process enclosures in the event of a failure of the portal closure.

4.4.4 Fume Hood Airflow Requirements

The airflow into fume hoods should be 90 $\pm$ 10 fpm face velocity. Individual measurements should be above 60 fpm and less than 125 fpm.

In-place testing on a representative sample of fume hoods shall be performed using American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) Standard 110, Method of Testing Performance of Laboratory Fume Hoods. The testing is required to determine the effects of supply air, traffic, and door openings upon the open-face fume hood while an operator is located in front of the hood. Adjustments of the face velocity may be warranted as a result of the in-place testing.

Usually baffling the supply air and locating the hood properly in the room (away from doors and traffic lanes) will correct unwanted drafts without changing the exhaust airflow rate.

New hoods should have features such as an air foil sill, an air bypass that allows a reasonably constant exhaust flow rate regardless of sash position, and no integral auxiliary air.

4.5 Nuclear Facility Ventilation Compartmentalization Requirements

4.5.1 Primary Confinement

Gloveboxes and shielded cells shall be exhausted through a primary confinement exhaust system and shall be located within a secondary confinement area.

4.5.2 Primary and Secondary Confinement Isolation

To minimize the extent of contamination during accidents, nuclear facility ventilation systems shall provide the capability to isolate the primary confinement from the secondary confinement and/or to isolate portions of the primary confinement from the remainder of the area.

Compartmentalizing of the confinement zones should be considered to allow for the isolation of a workstation or different enclosures within a workstation.

4.5.3 Specific Airlock Ventilation Standards

Airlock design is an important feature of a nuclear facility.

- Airlocks between primary and secondary confinement shall be equipped with sealed and interlocked doors.

- Enclosed vestibules (known as airlocks) between tertiary and secondary confinements should allow air to pass under the doors. Doors should have a 3/4-inch undercut and should not be sealed with a gasket. Additionally, back-draft dampers located above the doors aid the air balancing operation.

- A properly designed enclosed vestibule should be about 10 feet long and have about 500 cubic feet per minute (cfm) flowing through from the tertiary to the secondary confinement.

In the case of an outside door opening into secondary confinement, the outside door should be sealed with a gasket, and the vestibule should be supplied with 500 cfm at the outside wall end if the door is intended to have regular traffic.

- If intended for emergency use only, a sealed airlock should be used.

- Airlocks and enclosed vestibules shall be equipped with door interlock alarms.

4.6 Ventilation Control System Requirements

1. Automatic controls capable of being manually overridden should be provided to give flexibility of operation.

2. Provisions should be made for the independent shutdown of portions of the ventilation system when this could be advantageous to limit the consequences of accidents.

3. Adequate instrumentation shall be provided to ensure correct interpretation of system condition and operation under both normal and emergency situations.

4. Controls shall be chosen for maximum reliability and fail-safe operation in critical locations. Safety class electrical equipment shall meet the requirements of MRP 5.46, "Safety Classification of Systems, Components, and Structures," as determined by the facility safety analysis report (SAR).

5. Control of the ventilation system during normal and abnormal operating conditions should be from a centralized location within the facility, with instrumentation that monitors similar parameters grouped together.

6. The maintenance of the pressure gradient is more important than the absolute differential pressure. Control systems shall be designed to prevent hunting or oscillations that could present a reverse flow condition. Header systems that use atmospheric pressure as a reference pressure and that are unstable in the wind often successfully use fixed dampers throughout the exhaust system, except for an automatic constant-volume control of the total exhaust flow rate.

7. Operational noise levels shall be kept within Occupational Safety and Health Act guidelines. Exceptions shall be approved by Industrial Safety before operational testing.

4.7 Instrumentation and Control Requirements

1. The ventilation system shall be appropriately instrumented and alarmed to report and record its status. Table 4-2 provides the minimum requirements.

2. The ventilation system shall be appropriately equipped to facilitate acceptance testing and periodic or continuous surveillance. Table 4-3 provides recommendations. Systems shall be maintainable, testable and actions verifiable.

3. Ancillary equipment essential to air cleaning and proper functioning of the ventilation systems shall be equipped for operational and surveillance testing.

4. Permanently installed sample probes shall be designed to obtain a representative sample of the duct contents as described in ANSI N13.1-1969, Guide to Sampling Airborne Radioactive Materials at Nuclear Facilities, Section 4.2.

5. Permanently installed pitot tube ports should be located in primary confinement exhaust ductwork downstream from the first testable stage of high-efficiency particulate air (HEPA) filtration. The appropriate pitot traverse requirements are defined in the ASHRAE Handbook, Fundamentals Volume, 13.14.

6. Supply air drafts should be avoided when locating room continuous air monitor (CAM) sensors. Testing has shown that the quickest response time is obtained by locating the sensor near a secondary air jet (such as below a supply air outlet).

4.8 Requirements for Ventilation Air Supply Systems

1. Outside air intakes shall be located to minimize the intake of building exhaust air. Building design shall consider the airflow around the structure to eliminate crossflow between the intake and exhaust systems.

2. During freezing weather conditions, hoarfrost can develop and block off the outside air intakes, causing severe ventilation balance shifts. A defrosting method shall be installed. One method of defrosting the inlet screen is to sequentially bleed supply air backwards through a non-operating supply air fan by opening the discharge damper about 10%.

3. Supply air fans shall automatically stop and alarm when insufficient exhaust fan capacity exists or there is a potential for the loss of confinement pressure differentials.

4. The location of supply outlets and exhaust inlets to primary and secondary confinement should be chosen to provide a generally downward flow of air.

5. The supply outlet design should provide for a uniform distribution of air. In rooms containing open-face fume hoods, the supply air drafts near the hood face shall be limited to 50% of the hood inlet velocity at all measurements.

6. Supply system connections to primary confinement shall be equipped with HEPA filtration and isolation dampers as close to the confinement boundary as possible.

7. System requirements shall accommodate the design criteria established in DOE-RL Order 6430.1C, Hanford Plant Standards (HPS) Program.

8. Occasionally, processes in primary confinement require an inert atmosphere for proper operation. Maintaining an inert atmosphere normally requires a closed-loop system with feed and bleed, at least two stages of HEPA filtration, a purification stage and, often, a moisture-removal stage. Oxygen detectors with low-level alarms shall be placed in any confined working space where the inert atmosphere could accidentally displace the oxygen.

4.9 Functional Requirements for Ventilation Exhaust Systems

1. The primary function of HEPA filtration is to remove airborne particulate contamination from the ventilation system effluent. The exhaust system shall be designed to collect and adequately remove radioactive particulates to meet the discharge requirements (such as in WHC-CM-7-5, Environmental Compliance) for normal operations and the governing SAR for accidents. Usually HEPA filters are used for the particulate removal; however, other devices (such as sand filters) can be used.

2. The exhaust system shall be designed to prevent the spread of contaminated air into areas of less potential contamination.

3. Ducts serving primary confinement areas should not connect with ducts serving other areas unless the primary ventilation air stream has passed through at least one testable stage of HEPA filtration.

4. The exhaust systems for a building shall be coordinated with the air supply system to maintain adequate pressure differentials and airflow under normal and abnormal operating conditions including a DBA as defined in the facility SAR. Provisions for long-term shutdown should be made to be able to isolate the supply and exhaust systems that serve primary or secondary confinement by using low-leakage dampers and valves.

5. The facility exhaust fans shall be located downstream of final HEPA filter banks and provide sufficient redundancy to maintain the total exhaust flow rate during normal operation and maintenance.

6. Commercially available HEPA filter housings shall meet the requirements of American Society of Mechanical Engineers (ASME) N509, Nuclear Power Plant Air Cleaning Units and Components. Primary and secondary confinement exhaust system HEPA filters shall be designed for safe and convenient changeout by maintenance personnel.

7. Nuclear facilities shall be designed with redundant exhaust fans and filter systems to facilitate maintenance and filter changes without system performance degradation.

8. Primary and secondary exhaust ductwork passing through fire walls shall be constructed to resist the effects of a fire, and shall contain no fire dampers.

9. The air cleaning devices in the exhaust system should be placed within a secondary confinement zone.

10. Elements of the exhaust system that are located out-of-doors shall be protected from damage by weather and surrounding work activities (particularly moving vehicles).

11. The absolute pressure in a duct that contains contaminated air should be less than the absolute pressure of the area(s) through which it passes.

12. Safety class components of the ventilation system identified in the SAR that are required to remain in operation shall be supplied with appropriate power.

13. Contaminated exhaust streams shall not intentionally be diluted with uncontaminated streams for the purpose of complying with exhaust discharge requirements (such as WHC-CM-7-5,

Section C.4.2.1.8). The exhaust from primary confinement may, however, join the facility exhaust upstream of the final stage(s) of HEPA filtration.

14. Circular ducts of all-welded construction should be used for primary confinement exhaust systems to minimize particulate settling and ease of cleaning. The longitudinal seams should be placed in the top quadrant of the ductwork.

15. Exhaust stacks shall be designed and constructed in accordance with the ASHRAE Handbook, Equipment Volume, Chapter 26.

16. The capacity of the exhaust fan(s) shall be sufficient to maintain design flow rates throughout the range of dust loading on the filters, to a maximum of 4 inches water differential pressure. Inlet vane dampers should be used to accommodate the variation in required fan performance. No damper in the exhaust shall be allowed to automatically close during an upset condition.

17. The HEPA filters shall be protected from moisture caused by wet or humid conditions.

18. Exhaust ducts shall be constructed of noncombustible, easily decontaminated materials.

19. Acoustic linings, thermal insulation, and similar materials shall not be applied to the interior surfaces of primary or secondary confinement exhaust ducts or housings. Materials applied to the exterior of ducts and housings shall be noncombustible and shall allow access to duct accessories.

20. Adequate clearance for maintenance shall be provided upstream and downstream of filters in built-up filter housings (those made up of more than one filter in series). Permanent stairs and walkways should be provided for banks more than three HEPA filters high.

21. An injection port for an aerosol challenge agent shall be located far enough upstream of a testable HEPA filter to provide good mixing with the exhaust air, in accordance with ASME N510, Testing of Nuclear Air-Cleaning Systems. Withdrawal ports shall be provided immediately upstream and downstream of each testable bank of HEPA filters to determine the filter leak rate.

22. Exhaust from contaminated process equipment shall be HEPA filtered before it is injected into facility exhaust ducts.

23. Use of vacuum pumps requiring oil in systems which may become contaminated is strongly discouraged. If acceptable alternatives cannot be found, the pump discharge shall be treated to eliminate oil vapors and mists. All process vacuum piping systems should be monitored and filtered by HEPA filters upstream of the pumps.

4.10 Ventilation System Filtration Requirements

4.10.1 HEPA Filters

The HEPA filters shall meet the size, construction material, test, and qualification requirements of one of the HPS (RL 6430.1C, HPS-157-M through HPS-163-M).

4.10.2 In-Place Filter Testing

A minimum of one aerosol (Emory 3004 or similar challenge agent) testable HEPA filter shall be located in the exhaust system of any facility expected to contain radionuclides.

4.10.3 Filter Specifying

Defining the number of HEPA filters required for primary confinement is necessarily subjective and depends upon experience and judgment. Table 4-4 is presented as a guide for adding extra stages of filtration beyond those required for the basic facility. The radioactive materials are the maximum quantities expected to be contained within the particular glovebox group serviced by a combination of HEPA filter stages.

Experience demonstrates that this guidance, based upon conservative assumptions, will normally provide adequate primary confinement filtration. Generally, a non-testable HEPA filter is provided at the source to prevent excessive duct contamination. The facility shall have at least one (usually two) stage of testable HEPA filters in addition to the extra HEPA filter stages given in Table 4-4.

4.10.4 Release Parameters

Assumptions for releases are as follows:

- Inefficiency of each testable HEPA filter stage is 3×10^{-4} for 0.3 micron sized particles.
- The release fraction is the routine daily fraction of the total source term released to the first testable HEPA filter.

4.11 Ventilation Duct Routing Requirements

1. The testable HEPA filters of the primary ventilation system and all downstream ductwork, including the exhaust fan, should be located in secondary confinement space.
2. Penetrations of the building by potentially contaminated ducts shall be kept to a minimum and shall not compromise radiation protection.
3. Penetrations shall be designed to allow the essential system components to continue to function or fail safely during accidents.

4.12 Requirements for Use of Gaseous Adsorbers

1. The use of hazardous chemicals in solutions shall be minimized, and the use of carcinogenic chemicals should be avoided.
2. Adsorbent beds shall be designed to facilitate replacement and/or regeneration of the adsorbent. The adsorbent shall be compacted to a uniform density. Vertical variations shall only result from the need for the lower portion of the bed to support the weight of the adsorbent above it.

3. All materials in contact with the adsorbent must be appropriate corrosion-resistant material.

4. The adsorbent bed shall be arranged to preclude air bypassing the bed.

5. Screens shall be supported by stiffeners that are external to the adsorber bed to ensure uniformity and integrity of the bed.

6. Joints sealed with gaskets, caulk, or elastomeric materials shall not be used between the upstream and downstream sides of the adsorbent bed, frames, or any part of the installation, except for removable test canisters.

7. The adsorber system shall be designed for in-place performance testing of the adsorber bed and for collecting samples of the adsorbent for laboratory analysis without sacrificing performance of the system.

8. To preclude adsorbent ignition or desorption, adsorbent systems shall be designed to dissipate the anticipated maximum trapped material decay heat. Airflow through the system shall not be the only heat removal mechanism employed when heat removal is required.

9. Pretreatment (usually scrubbers) shall be used to protect the adsorbent against poisoning by trace chemicals such as organics, nitrous oxides, and fluorides when they are present in the exhaust stream.

10. Adsorbents shall be protected against excessive accumulation of water.

11. Pretreatment scrubbers shall be constructed of materials compatible with the effluent, scrubbing, and decontamination solutions.

12. The scrubber solution chemistry shall be monitored and controlled when required to ensure optimum scrubber efficiency.

13. The liquid wastes generated from the scrubber operations shall be routed for recovery of materials to produce a solution that can be satisfactorily released in accordance with environmental regulations.

14. Scrubbers should be designed to minimize the entrainment of liquid droplets to protect downstream materials.

15. The design shall minimize the formation of gaseous radioactive material during disposal of the scrubber solutions.

16. The disposal of scrubber solutions shall be designed to prevent explosion hazards due to the formation of explosive gases or compounds, such as metallic oxides and organic nitrates.

17. Contaminants in exhaust gases shall be evaluated when a radioiodine adsorber is selected. Activated carbon shall be the preferred adsorbent except under the following conditions:

    - Where perchloric acid or other strong oxidizers will be present

    - Where oxides of nitrogen or organic solvents will be present.

In those cases (a or b), silver zeolite adsorbent or a silver reactor shall be used.

18. Activated carbon adsorbers shall meet the following criteria:

- Pleated-bed adsorber cells shall meet the requirements for Type I cells of Institute of Environmental Science, IES-CC-RP-008-84, High Efficiency Gas-Phase Adsorber Cells, and shall be filled with an adsorbent meeting the requirements of DOE RDT Standard M 16-1T, Gas-Phase Adsorbents for Trapping Radioactive Iodine and Iodine Compounds.

- Activated carbon adsorber beds shall be at least 2 inches deep and shall provide a retention time of at least 0.25 second.

- The activated carbon bed shall be equipped with removable test canisters, which shall:

  a. Be located where they will be exposed to the same airflow conditions as the adsorbent in the main system

  b. Have the same adsorbent bed depth

  c. Be filled with representative adsorbent from the same lot of adsorbent as that of the main system.

- The activated carbon adsorbers shall be preceded and followed by HEPA filters.

4.13 Requirements for Locating Filter Units

1. Exhaust fans and testable HEPA filters shall be located outside of primary confinement.

2. Exhaust fans shall be located downstream of the air cleaning filters to minimize contamination of the air moving equipment and avoid pressurizing contaminated ducts.

3. Prefilters shall be provided to reduce dust buildup on the exhaust system HEPA filters.

4. The preferred use of non-testable HEPA filters (those filters used to remove gross contamination and not tested with an aerosol challenge agent) shall be to reduce contamination in the associated ductwork. Exhaust duct inlets from gloveboxes and hot cells shall be equipped with non-testable HEPA filters.

5. The testable stages of high-efficiency air cleaning devices should be located within secondary confinements to reduce worker exposure during maintenance and testing. If a stage of air cleaning can accumulate radioactive materials that exhibit high-exposure potential, the location shall be in a radiation area dedicated to the air cleaning system and remote changeout capability should be provided. The design of the air cleaning system shall incorporate shielding as necessary when the air cleaning devices may become a significant source of radiation.

6. The ventilation in areas that contain air cleaning devices shall be arranged to remove airborne materials that may be released during maintenance and filter changes. The design of the air cleaning system should consider bagout filter housing, self-contained filters, and/or other features that allow installing temporary enclosures (such as greenhouses) for changing contaminated components of the air cleaning system.

7. The first testable stage of HEPA filters for primary confinement shall be located close to the exhaust inlet to prevent airborne radioactive materials from entering a major portion of the ventilation ductwork.

4.14 Filtration Testing Requirements

1. The HEPA filters may be installed in either a testable or non-testable configuration. Testable refers to the ability to evaluate the filter efficiency in removing an aerosol challenge agent.

2. The HEPA filter acceptance test shall be performable when the filters are in place in the exhaust system.

3. In a safety evaluation, credit for reducing environmental releases will only be given to the filters and filter banks that can be tested.

4. Both testable and non-testable HEPA filters shall be sealed to prevent air leakage bypassing the filters.

5. All HEPA filters shall be tested by the Hanford Environmental Health Foundation before installation and use in either testable or non-testable locations.

6. High-efficiency air cleaning systems for restricting environmental releases shall be rigorously designed to allow convenient and reliable in-place testing of each testable stage of filtration. Testable stages shall be provided with aerosol injection ports and sampling ports. Refer to ASME N510 for additional criteria for in-place testing design features.

4.15 Recirculating Air System Requirements

1. Recirculating air ventilation systems are frequently included in new building design as an energy conservation measure. Particular care should be exercised in the design of recirculating air systems for areas where radioactive materials will be handled. Recirculating air ventilation systems shall ensure confinement of airborne radioactive materials, prevent the buildup of airborne materials in work areas, and remove any radioactive materials that may become airborne.

2. Designs shall ensure that potential changes in airflow during a DBA will not cause airborne radioactive materials to migrate into uncontaminated areas.

3. Return air streams to be recirculated from secondary confinement shall be filtered with two testable stages of HEPA filters and a CAM. The system shall automatically switch to a once-through mode of operation whenever the radiation monitor detects contamination

downstream of the first HEPA filter stage. A manual control of the ventilation mode shall be provided.

4. Sampling capability shall be provided between the two stages of HEPA filters to aid in detecting airborne radionuclides passing the first stage filter.

5. When contamination is detected downstream of the first HEPA filter bank, the CAM instruments, which shall be equipped with alarms and controls, shall automatically change the ventilation system to supply clean air to the work area(s) and filter the contaminated exhaust air through HEPA filters.

6. Air exhausted during the single-pass condition shall be filtered through HEPA filters to meet the exhaust discharge requirements before release to the environment (such as in of WHC-CM-7-5).

4.16 Requirements for Emergency Considerations

4.16.1 Single Component Failure

The ventilation system shall be designed to adequately confine and restrict release of radioactive materials, when a single component fails.

4.16.2 Safety Class Components

All safety class elements of the system essential for restricting releases and maintaining confinement (as determined by the SAR) shall be designed to remain functional or safely shutdown during accidents. Redundant capability and/or spare capacity shall be provided and maintained for active safety class components. Instrumentation for monitoring the function of active safety class components shall also be designed to remain functional during accidents.

4.16.3 Special Power Supplies

Emergency, standby, or uninterruptible power shall be provided to the exhaust ventilation system as determined by the facility SAR. This power shall be independent of the normal power supply and shall have the capability to be tested periodically. Such tests should not interrupt the normal operation of the system or jeopardize the system's safety functions.

4.16.4 Non-Safety Class Components

Non-safety class ventilation systems shall be designed to fail in a safe mode. Visible or audible alarms shall be provided to indicate the failure of a critical component or the development of a potentially serious condition, such as the loss of pressure differentials, plugging of HEPA filters, or excessive release of radioactive materials.

4.17 Fire Protection Requirements for Ventilation Systems

1. Fire detection and suppression equipment shall be provided in primary and secondary confinement as needed to ensure the operability of the air cleaning system during a design basis fire.

2. Appropriate fire protection equipment shall be provided to protect the final bank of testable HEPA filters from a design base fire. An ember screen, spray, and demister are commonly used.

3. If water cooling or suppression systems are used, a demister or prefilter mist eliminator shall be provided to protect the HEPA filters from impingement of water droplets. Provisions shall be made for removing and safely confining all water that may be delivered into contaminated portions of the ventilation system. Drains and storage tanks shall be designed to provide safe geometry when criticality is a concern.

4. All fire suppression equipment shall be designed for fail-safe operation. The fail-safe mode shall be determined by the facility SAR.

5. The ventilation system shall be designed to minimize the spread of fire from the hood, compartment, or room of origin. Use of downdraft airflows in process enclosures should be considered to reduce the potential for fire and contamination spread.

6. Potential explosion and sudden release of high pressure gases from storage tanks and pressurized gas supply systems shall be considered for design base fires.

4.18 ALARA Applications

1. The HEPA filters with a potential to exceeding 5 mSv/h on contact should be capable of remote exchange.

2. The design shall ensure that the maximum individual dose expected during any filter change will be ALARA.

3. Adequate space (including step-off pads) shall be provided around filter housings, dampers, and controls to permit access for test equipment, personnel, and materials required for filter changes.

4. Filter boxes should be located in such a manner that ladders or other temporary structures are not needed for filter changes or testing.

5. Surfaces of exhaust ducts, filter housings, equipment, walls, ceilings, and floors where contamination could accumulate shall be non-porous, free of cracks and crevices, smooth, and finished to facilitate decontamination.

6. Adequate lighting shall be provided to minimize the time necessary for maintenance.

7. System design shall incorporate features that ensure continuous containment of radioactive materials during filter changes.

8. If bypass systems are installed, they shall meet the same criteria as the system being bypassed.

Table 4-1. Recommended Interzone Pressure Differentials.	
Zone Boundary	Pressure differential (inches water)
Atmosphere to tertiary zone	0.03 inches water
Tertiary to secondary zone	0.1 inches water
Secondary to primary zone	
• Glovebox or hot cell with manipulator	0.7 to 1.0 inches water
• Hot cell without manipulator	1.0 inches water
NOTE: Pressure differentials shown are approximate. Actual pressure differentials shall be by analysis.	

Table 4-2. Ventilation System Recommended Instrumentation Requirements.	
Measurement	Function
Continuous air monitor	I, R, HA, MA
Exhaust flow	I, R
Pressure drop (each HEPA filter bank)	I
Differential pressure, primary/secondary zone	I, LA
Differential pressure, tertiary zone/tertiary zone	I, LA
Differential pressure, tertiary zone/atmosphere	I
Supply and exhaust fan status	I, MA
I = Indicator R = Recorder HA = High alarm LA = Low alarm MA = Malfunction alarm	
NOTE: Analysis is required to determine the adequacy of the recommended instruments.	

Table 4-3.
Ventilation System Recommended Surveillance Requirements.

Measurement	Function
Airborne radioactivity, room	Continuous air monitor
Airborne radioactivity, process glovebox and hood exhaust downstream of testable HEPA filters	Duct sample
Airborne radioactivity, facility exhaust vents and stacks	Stack sample
HEPA filter in-place leak test	Challenge aerosol injection, uniform mixing, upstream and downstream sampling
Adsorber in-place leak test	Freon injection, uniform mixing, upstream and downstream sampling
Adsorber laboratory test	Test canisters
NOTE: An analysis is required to determine the adequacy of the recommended measurements.	

Table 4-4. Minimum HEPA Filter Criteria for Primary Confinement.

Two Additional Testable Stages[a,b]			One Additional Testable Stage[a]		
RD	D	LD	RD	D	LD
HT $\leq$100μCi	$\leq$10mCi	$\leq$10Ci	HT $\leq$1μCi[d]	$\leq$10μCi[d]	$\leq$10mCi
MT $\leq$100mCi	$\leq$10Ci	$\leq$1KCi	MT $\leq$10μCi[d]	$\leq$10mCi	$\leq$1Ci
			LT $\leq$1mCi	$\leq$1Ci	$\leq$100Ci

A minimum of two testable and one non-testable[c] stages of HEPA filtration are normally used for contamination control for gloveboxes, hot cells, etc.

Symbol	Assumed release fraction to first filter
RD = Readily dispersible	10^{-3}
D = Dispersible	10^{-5}
LD = Limited dispersible	10^{-7}
HT[e] = High radiotoxicity	
MT[e] = Moderate radiotoxicity	
LT[e] = Low radiotoxicity[e][f]	

[a] Refers to testable filter stages in series.

[b] Additional stages in series shall be required for higher source terms or if analysis of potential releases indicate a need for extra protection.

[c] Non-testable filters will be used at the duct entry to reduce levels of contamination that may accumulate in ducts or air cleaning equipment.

[d] Low specific activity.

[e] From 10 CFR 20, Appendix C:

HT is 10 mCi or less
MT is 100 nCi
LT is 1,000 mCi.

[f] Natural uranium and thorium are considered low-radiotoxic materials because of their low specific activity.

5.0 GLOVEBOXES

5.1 INTRODUCTION

Gloveboxes are used to provide confinement of dispersible radioactive materials. A confinement system is a barrier or a series of barriers including ventilation systems used to enclose and to minimize the release of radionuclides during normal and abnormal conditions.

5.2 GENERAL CONSIDERATIONS

1. The primary consideration in the design of a glovebox shall be maintaining confinement of radioactive materials while providing for a means of working with them.

2. The glovebox shall be designed to accommodate the work process or operations for which it is intended. Sufficient work space to permit removal of materials and easy personnel access shall be provided.

3. The glovebox support structure shall be able to adequately support the glovebox and the maximum inventory of process materials and equipment located in, and shielding attached to, the glovebox. The glovebox support structure shall be designed in accordance with the Uniform Building Code lateral force requirements as a minimum, and to the Functional Design Criteria for the facility if specified therein. The support structure should accept the DBA condition without breaching the confinement.

4. The size and the dimensions of the glovebox shall be determined using the human engineering data given in Appendix A in order to accommodate the worker size range specified in Appendix A.

5. The worker shall be able to access any part of the glovebox interior either directly or with the use of accessories.

6. The primary confinement barrier shall be designed to protect personnel from contamination during normal and abnormal operations. The design of process system enclosures shall provide confinement during normal operations. (DOE Order 6430.1A)

7. All penetrations into the primary confinement barrier (e.g., test ports, ducts, valves, and windows) shall have positive seals to prevent the migration of contamination and should be tested in place for leakage before use. (DOE Order 6430.1A)

8. Rough surfaces, square corners, cracks, crevices, and absorbent materials shall be avoided in the primary confinement areas. Disposable linings, covers, coatings, and/or easily decontaminated surfaces shall be used in the primary confinement enclosure where practical.

9. Noncombustible and corrosion-resistant materials shall be used in the construction of the confinement system. (DOE Order 6430.1A)

10. Service pipes, conduits, and duct work should be minimized to facilitate the maintenance and decontamination of confinement systems.

11. Fixed modular construction should be used where possible with standardized attachments for installation and removal.

5.3 SPECIFIC CONSIDERATIONS

5.3.1 LOCATION

Gloveboxes shall be located inside a radiation area (controlled area). In some instances (large glovebox processes), the workstation may be separated into an operating area and a service area.

5.3.2 CONFINEMENT

1. The glovebox shall be designed to operate at a negative pressure of 0.5 to 0.7 inch of water relative to the room in which it is located. Section 4.0 shall be followed in this regard.

2. The glovebox shall incorporate differential gauges to monitor interior pressure relative to the room in which it is located. The gauges shall be located where glovebox operators and maintenance personnel can readily view them. Differential pressure alarms shall be provided as specified in Section 4.0.

3. The glovebox, when assembled and all penetrations are blanked off, shall have an atmospheric leak rate less than 0.3 volume percent per hour, for 12 hours, at an initial negative pressure differential of 4 inches water. Special interior atmospheres may require more stringent leakage criteria to prevent degradation of the glovebox atmosphere.

4. The glovebox ventilation system shall prevent the release of radioactive material under normal operating conditions and under a DBA due to penetration into the glovebox. See WHC-CM-4-46, Nonreactor Safety Analysis, for DBA definition.

5. The number of penetrations for glovebox services should be minimized. Fittings chosen shall provide a positive seal to prevent migration of contamination.

6. Penetrations for rotating shafts should not be permitted except where there is no other alternative.

7. Supply air to a glovebox shall be filtered through a HEPA filter for the prevention of contamination spread in the event of an airflow reversal.

5.3.3 MATERIALS

1. Materials used for the interior of the glovebox, and for accessory equipment in direct contact with the interior, shall offer the structural strength, corrosion resistance, resistance to radiation and hazardous material-caused degradation and radiation shielding required by the intended use. An electropolished, stainless steel surface is usually superior to any other surface.

2. Only noncombustible materials or fire resistive materials shall be used in glovebox construction. (International Atomic Energy Agency, (IAEA) No. 30)

5.3.4 WINDOWS

1. Windows shall be placed, angled, and sized to minimize "blind spots" for the worker, and to maximize visibility and lighting.

2. The percentage of the glovebox wall area devoted to windows shall be maximized (to the extent permitted by seismic requirements [in accordance with the SAR] and radiation shielding) to enhance interior visibility.

3. Window material shall be noncombustible or fire resistant and resistant to mechanical shock. Where practical, window material shall be glass (e.g., wire reinforced, laminated safety or safety plate). Where glass window material is inappropriate due to design or operating conditions, polycarbonates (Lexan) shall be approved on an individual basis by Safety management during a design review. Windows located on top of the glovebox, or where extra strength is required, shall be made of wire-reinforced plate glass. (SD-TI-105 Material Selection for Glovebox Windows and Laboratory Hood Panels)

4. Windows shall be securely fastened by mechanical means. Gasket and sealant material shall be resistant to deterioration by chemicals and radiation.

5. Features to facilitate window removal and replacement shall be incorporated.

5.3.5 PORTS

1. Ports shall allow replacement of gloves or bags while maintaining contamination control.

2. Ports shall be securely attached by mechanical means. The design shall include features (such as double ridges on port rings) to assure maintenance of confinement during glove and bag changes. (DOE Order 5480.1)

3. Glove ports shall be located so that all areas of the glovebox interior can be reached either directly or with the use of accessories.

4. The need for two-handed reach, the depth of reach, and positioning of glove ports with respect to other glove ports accommodated by the design shall take into account the anticipated operations in each glovebox. Human factors data supplied in Appendix A shall be used to determine optimal positioning of the glove ports.

5. Gloves shall be sealed with materials that will resist deterioration by chemicals and radiation. (IAEA 30)

5.3.6 INSERTION/REMOVAL SYSTEMS

1. Insertion and removal systems shall ensure maintenance of dp, special atmospheres, and contamination control during equipment entry and removal operations.

2. Glovebox internal space shall be sufficiently large to accommodate anticipated insertion and removal of equipment and materials without damage to the glovebox, equipment or processes contained inside.

3. Airlocks should not be incorporated into gloveboxes where large quantities of uncontained, dispersible radioactive materials are anticipated. Past experience has indicated that airlocks

become contaminated under these conditions and no longer serve a functional purpose. Bag in/bag out is preferable in this situation.

4. Air shall always flow into the glovebox interior. The airlock shall have an air (or gas) intake and exhaust system that is separate from that of the glovebox. Airlocks provided for gloveboxes with inerted atmospheres shall include gas-purging systems. Sphincter seals may be incorporated into gloveboxes where there is little potential for large quantities of dispersible materials. A latching lid shall be provided to cover the exterior of the sphincter port.

5. Only equipment essential to the function of the glovebox should be inside the glovebox. Equipment to be located inside the glovebox must be designed to minimize maintenance requirements and should be designed for inplace maintenance (DOE Order 5480.1A). Equipment shall also be designed (or chosen) to minimize contamination traps, facilitate decontamination, and to simplify decommissioning.

6. Equipment shall be designed to preclude sharp corners, barbs, or pointed parts and pinching points that could puncture glovebox gloves or skin. All corners shall be rounded, burrs removed, etc.

7. Bag in/out ports should be sufficiently large so that most, if not all, equipment can be inserted or removed without necessitating window removal.

8. Bag-out ports, sphincter seals, and airlocks shall be designed and installed to facilitate the introduction or removal of needed equipment and supplies compromising contamination control. Airlocks shall be designed and balanced to be at a negative pressure with respect to the workstation and positive pressure with respect to the glovebox.

5.3.7 LIGHTING

1. At a minimum, 100-foot candles (1,076 lux) of illumination shall be provided on all work surfaces for close work, and 50-foot candles (538 lux) for general illumination.

2. Lighting shall not jeopardize window integrity by the heat loading.

3. Lights shall be positioned to minimize window glare.

4. Provisions shall be made to allow lamp and light fixture changes without breaking confinement.

5. Wire-reinforced glass shall be used for all windows dedicated to lighting.

6. Lighting fixtures shall be mounted on the glovebox exterior to the extent practical.

5.3.8 SHIELDING

1. Gloveboxes shall include shielding necessary to conform with Section 8.

2. Shielding material shall be noncombustible or, if combustible, encapsulated and sealed in noncombustible material.

3. The impact on visibility into the glovebox due to added shielding should be minimized.

4. All penetrations should have offsets to minimize radiation streaming or include sufficient shielding material to reduce streaming to acceptable levels.

5. Gloveboxes should be provided with covers or plugs for each port. The plugs or covers shall provide shielding equivalent to the glovebox walls.

6. Actual sources inside the glovebox should be shielded rather than the glovebox itself.

5.3.9 VENTILATION

The ventilation system (including supply and exhaust of gaseous materials) shall conform with the requirements of Section 4.0.

5.3.10 SERVICES/UTILITIES

1. Utility Services shall not degrade confinement and control of radioactive materials.

2. Any gas supply system connected directly to the glovebox shall have features to prevent flow in excess of exhaust capacity, to minimize the effects upon the pressure differential specified in Section 4.0, and to prevent backflow of contamination.

3. High pressure lines shall have flow limiters to minimize the possibility of pressure in excess of that in the room.

4. Interior services shall be supplied with quick acting automatic or manual shutoffs in an accessible location.

5. Process piping to gloveboxes should be equipped with backflow preventors and shall be of corrosion-resistant construction (e.g., welded stainless steel). The type of backflow preventor depends upon specific application and will be specified during design.

6. Occupied spaces adjacent to gloveboxes shall be provided with appropriate radiation-monitoring and air-monitoring systems. Space for portable radiation survey instruments shall also be provided at glovebox stations.

7. Gloveboxes shall be equipped with fire detection and suppression devices.

8. Vacuum pump exhaust shall be discharged to primary confinement ventilation filtration.

5.3.11 WASTE SYSTEMS

1. The design of gloveboxes shall include means to control and minimize the release of radioactive materials to the plant waste systems during anticipated steady state and transient conditions.

2. The gloveboxes shall include a means of conveniently and safely removing solid and liquid wastes from the work area. Three methods to consider are the incorporation of a basement

for temporary storage, a large canister port in which to hold waste for early disposal, or bag ports.

3. The method of removing waste from the glovebox shall take into account contamination control, personnel exposure, criticality safety, time factors, personnel safety, fire protection, and convenience.

4. Design of glovebox systems for handling airborne effluents shall conform with Section 4.0.

5. Design of glovebox systems for handling liquid wastes shall be compatible with Section 11.0.

5.3.12 MONITORING AND ALARM SYSTEMS

1. Gloveboxes shall be equipped with devices that annunciate audibly upon failure to maintain proper pressure differentials (i.e., -0.5 in. wg below room pressure). Visual alarms should also be considered, especially in high noise areas.

2. Airborne radioactivity alarms shall conform with the requirements of Section 4.0.

3. Alarms shall annunciate both locally and to a central area, if provided.

4. Alarms located in a central, continuously occupied area shall, as a minimum, identify the room from which the alarm originated.

5. Switches that activate a signal in a central control area (whose purpose is to summon help) should be located in areas containing gloveboxes. The switches should be clearly marked as to their function and should have a manual reset capability. At least one switch per contamination/ventilation area should be provided.

5.3.13 DECONTAMINATION AND DECOMMISSIONING

1. The design of the glovebox and materials selected for construction shall take into consideration decontamination requirements. An electropolished stainless steel interior is usually superior both for routine decontamination and for decommissioning purposes.

2. Smooth surfaces, rounded junctions and corners, and nonabsorbent materials shall be provided.

3. The interior of all gloveboxes shall be smooth and free of crevices and sharp objects to facilitate decontamination (IAEA No. 30). Surface coatings may be applied to enhance corrosion resistance.

6.0 HOT CELLS

6.1 INTRODUCTION

This section contains radiological design criteria for hot cells which handle highly radioactive and dispersible materials. Hot cells shield and totally confine radioactive materials. They have manipulator systems, closed circuit television cameras, robotic systems, and in some instances, glove ports to allow remote work with highly radioactive materials. These criteria may not apply for totally contained sources (such as food irradiators, sealed cobalt sources, etc.). The criteria cannot cover all the possible situations that may arise. Therefore, for the final design, designers need to consider the specific mission of the hot cell and the behavior of the radioactive materials to be used.

6.2 DESIGN CRITERIA FOR HOT CELLS

6.2.1 GENERAL PRINCIPLES

1. Hot cells shall provide total confinement and adequate shielding so that highly radioactive and dispersible radioactive materials can be processed or otherwise used within acceptable dose rates to personnel. Acceptable dose rates are supplied in Section 8.0 of this design guide.

2. The hot cell structure, including access openings, shall be designed to maintain control over the release of radioactive material under DBA conditions as well as under normal operating conditions.

3. The hot cell shall be designed to keep personnel doses ALARA and to prevent accidental intrusion into the cell.

4. As much of the hot cell operating floor as possible, should be accessible by remote means. All areas of the hot cell walls and ceilings should be accessible by remote means.

5. All installed equipment in the hot cell should be reachable by remote means for routine maintenance purposes.

6. All installed equipment in the hot cell should be removable by remote means. If radiation levels can be eliminated or reduced sufficiently to permit personnel access, equipment may be designed for manual changeout.

7. The structure of the hot cell shall be adequately strong to support the hot cell and the maximum inventory of process materials and equipment located in the cell including the required shielding. The support structure shall be designed in accordance with the Uniform Building Code lateral force requirements as a minimum and to the Functional Design Criteria for the facility, if specified, herein. The support structure should accept the DBA condition without breaching the confinement.

6.2.2 VENTILATION

The ventilation system (including supply and exhaust of gaseous material) shall conform with the criteria of Section 4.0 of this design guide.

6.2.3 CONFINEMENT

1. Seals may have special requirements due to process and/or cell atmosphere requirements.

2. Seals shall be capable of withstanding a pressure differential of at least 10 inches wg.

3. Inner seal-windows shall be used to protect the window shielding from mechanical damage and cleaning agents.

4. The maximum leak rates should not exceed 1 percent of the cell volume in cfm for unlined cells and 0.1 percent in lined cells, at a negative 2 inches of water column.

6.2.4 LOCATION

The location of a hot cell within a facility shall conform with the requirements of Section 2.0 of this design guide.

6.2.5 HUMAN FACTORS

Human factors considerations shall be taken into account on hot cell designs. Information on human factors may be obtained from Appendix A, "Human Factors Considerations."

6.2.6 CONSTRUCTION MATERIALS

1. The main radiological considerations in the selection of materials to be used for hot cell walls (interior and exterior) should be shielding for the type and energy of radiation expected, resistance to the particular stresses imposed by the operations to be conducted, and strength. Materials used in constructing hot cells shall be capable of withstanding the anticipated environment (such as high radiation levels, corrosive agents, various chemicals, extreme temperatures, physical assaults, etc.)

2. Seals shall be constructed of radiation resistant materials.

3. Any paints or protective coatings used shall comply with ANSI, ANSI Standard N512, Protective Coatings (Paints) for the Nuclear Industry.

6.2.7 SHIELDING

1. Shielding shall conform with the criteria in Section 8 of this design guide.

2. Shielding material shall be noncombustible. Combustible shielding encapsulated and sealed in noncombustible material may be considered noncombustible after evaluation and concurrence by Safety management.

3. All ports and openings shall be shielded with plugs, covers, or lids with adequate shielding.

6.2.8 WINDOWS

1. Window shielding should provide radiation attenuation equivalent to the wall shielding. Concurrence of Safety management shall be obtained in all cases where this requirement cannot be met.

2. Windows shall be constructed of material(s) that are noncombustible, fire resistant and mechanical shock resistant as appropriate for the type of radiation encountered within the hot cell.

3. Windows and frame structures shall be stepped to prevent streaming and shine through the gaps between the window and frame and securely fastened by mechanical means with gaskets and sealant material resistant to deterioration due to process chemicals, materials, and radiation.

4. Gaps present between hot cell windows and frames before installation of gasket materials shall be minimized to facilitate window removal/replacement.

6.2.9 VISIBILITY

1. All portions of the hot cell interior should be visible, either directly (through shielded windows) or indirectly (e.g., through mirrors, periscopes, etc.) and with a minimum of distortion.

2. Windows and lights shall be positioned to maximize visibility.

3. Glare from the hot cell interior shall be minimized.

4. Lamps inaccessible to personnel shall be changeable by remote means. If radiation levels can be eliminated or reduced sufficiently to permit personnel access, lamps may be designed for manual changeout.

5. Sodium vapor lighting should be utilized where possible.

6. Closed circuit television cameras should be chosen for radiation resistance.

6.2.10 ACCESS PORTS

1. Access ports, including glove ports and bag ports, should not jeopardize contamination control.

2. The insertion and removal process shall be designed to prevent accidental exposure during and after transfer of items.

3. Use of access ports shall not jeopardize the pressure differential or ventilation parameters specified in Section 4.0, Paragraph 2.2.

4. Access ports shall be designed to prevent radiation streaming and to keep personnel doses ALARA.

5. Access ports should be located where traffic is at a minimum.

6. Means of transferring small items into the hot cell which do not require opening a large volume of the hot cell should be provided.

7. Access ports sufficiently large to remove all in cell equipment shall be provided.

8. Access ports shall be capable of withstanding a pressure differential of at least 10 inches wg.

6.2.11 PENETRATIONS

1. Penetrations such as services, utilities, and windows shall not be straight or angled directly into the hot cell. The penetrations shall be stepped, helical, tortured, etc.

2. Penetrations shall be sealed to maintain the leak-tightness specified in Section 4.0.

3. Flow limiters shall be used on high pressure lines to prevent pressurization of the cell in the event of failure of the line or flow controller.

6.2.12 WASTE SYSTEMS

1. Methods of safe removal of radioactive waste shall be included.

2. Radioactive liquid waste systems shall comply with Section 11.0.

3. HEPA filters shall be provided (as required in Section 4.0 of this design guide).

4. The HEPA filter shall be changeable by remote means. If radiation levels can be eliminated or reduced sufficiently to permit personnel access, filters may be designed for manual changeout.

5. The HEPA filter shall be capable of withstanding the expected environment inside the hot cell.

6.2.13 DECONTAMINATION AND DECOMMISSIONING

1. The hot cell shall be designed for repeated decontaminations of both the hot cell interior and installed equipment. The preferred interior finish is to fully line the inside with smooth stainless steel.

2. The interior surface of the hot cell shall be as smooth and free of cracks, crevices, and rough areas as possible and constructed from nonabsorbent materials.

3. Corners and junctions (where walls, floor and ceiling meet) shall be covered.

4. The hot cell should be capable of being remotely decontaminated.

5. The hot cell shall be designed considering future decommissioning of the facility.

7.0 SHIELDING

7.1 INTRODUCTION

It is a stated policy of the DOE that reduction of personnel radiation exposure to ALARA be incorporated into the design or modification of facilities and equipment. Current DOE policy on new facility design is that shielding shall be designed to limit the total whole body dose to less than 5 mSv per year. WHC has an administrative limit of 5 mSv per year. This should be compared with the current five rem per year operating limit for existing facilities. (10 CFR 835)

The purpose of the criteria presented here is to provide standard guidance for the design of nuclear radiation shields for new facilities.

7.2 PRELIMINARY CRITERIA

1. Preliminary (initial) shield design shall be based on Table 1. Dose rates in all cases are at the point of exposure. That is, where an individual will actually be working and some or all of his/her body will be exposed.

2. Initial design effort should be directed to the lower radiation level of Table 1 for each zone category. Even lower levels should be sought if they can be achieved within the principle of ALARA.

7.3 SPECIFIC CONSIDERATIONS

1. Penetrations through shielding materials, such as access ports, windows, ventilation ducts, conduits, or pipes, should have steps, baffles, or offsets to preclude radiation streaming. Penetrations through permanent shielding should be located as high as possible above accessible floor elevations.

2. Consideration should be given to radiation backscatter and air scatter of radiation.

3. Bricks used for shielding should overlap to prevent radiation streaming.

4. The selection of shielding should be based on the attenuation characteristics of the material with respect to the anticipated radiation sources.

5. Personnel entryways, labyrinths, and pathways leading to high radiation areas should be designed or shielded to adequately reduce direct and scattered radiation.

6. In facilities with a potential for criticality, staggered shielding walls shall be used to prevent streaming.

7. Consideration should be given to providing permanent shielding for use with radiation monitoring and survey equipment in controlled areas.

8. Shielding materials should be fire retardant or fireproof and should not produce toxic gases or smoke when heated.

9. Shielding materials should be located as near as practical to the radiation source.

10. The shielding material selected shall be structurally stable (i.e., not lose its effectiveness through sagging or creeping).

11. The use of radiation-resistant shielding material(s) shall be considered in areas of high radiation exposures.

12. Radiation shields, as opposed to liners, should not be used to contain or exclude gases, solids, or liquids in a shielded enclosures.

13. Where permanent shielding is impractical and operational or maintenance access is required, the distance between radioactive components shall be designed to permit installation of temporary shielding around items that contribute substantially to the dose rate.

14. Shielding structures should be designed in conjunction with process equipment and associated confinement equipment so that normal operation and maintenance activities can be performed in minimum time.

15. Floors shall be designed to bear the weight of the heavy shielding that may be required to minimize personnel exposure.

7.4 FINAL SHIELD DESIGN CRITERIA

The following relation will be employed as the final shield design criteria for the facility:

$$Hxi\ Ri/Nx \leq 5 \text{ mSv per year per individual}$$

Where the summation is over the i different category zones that are established throughout the new facility, Hxi is the total number of hours per year that all persons in craft or skill group x will spend in the i-th radiation zone whose design intensity is Ri mSv per hour and Nx is the number of members in the operating and maintenance crew who belong to craft or skill group x.

These relations can be applied during preliminary design of the facility as soon as the size of the operating and maintenance crew is established. This technique will reveal any gross imbalances in dosage received by different groups that might otherwise be overlooked. These imbalances are expected to occur only if any unusually high demand for radiation work is indicated for a particular craft or skill group. For example, the number of pipefitters required on the maintenance crew might be small, but most of their time might be utilized on high-level radiation zones. If the above relation for pipefitters indicates that they would average more than one rem per year, the final design would need revision to eliminate such an inconsistency.

Table 7.1 Shield Design Criteria

Zone Category	Access Time Allowed	Maximum (μSv per hour)
Uncontrolled Area	Full time	0.5
Controlled Area		
1	Full time	2.5
2	Less than 1 hour per day	20
3	Less than 1 hour per week	100
4	Less than 10 hours per year	500
5	No normal access permitted	> 500

Note: For design purposes the dose due to neutrons should be calculated by doubling the neutron quality factors (DOE Order 5480.11).

8.0 RADIATION GENERATING DEVICE

8.1 INTRODUCTION

Radiation generating device installations consist of x-ray generators, sealed gamma-ray sources, sealed beta ray sources, neutron generators, and/or particle accelerators and the protective characteristics inherent in their design to provide a safe radiological work environment. Radiation monitoring system requirements are applicable to all types of radiation generating device installations and are provided under general considerations.

Specific considerations are provided for the following types of installations:

- o X-ray and sealed gamma-ray source
- o X-ray diffraction and fluorescence equipment
- o Particle accelerators.

8.2 GENERAL CONSIDERATIONS

8.2.1 RADIATION MONITORING SYSTEMS

1. Area radiation monitors shall be provided in all enclosures that contain a radiation generating device and that are designed for personnel access.

2. The radiation monitoring system shall be intertied with an interlock system to cause the source of radiation to de-energize or return to a shielded position if there is a system single-mode failure.

3. The monitoring system shall include local readout of radiation levels and alarms at the monitor location readily visible to personnel.

4. The monitoring system shall include remote readouts and alarms at the control console.

5. Safety management shall approve the number, types, and locations of the radiation monitors.

6. For radiation generating devices that generate energies above 10 MeV, the need for a CAM and/or air sampling should be evaluated due to potential airborne activation products.

8.3 CONSIDERATIONS FOR SPECIFIC TYPES OF INSTALLATIONS

8.3.1 X-RAY AND SEALED GAMMA-RAY SOURCE INSTALLATIONS

The installations for x-ray and sealed gamma-ray sources are classified as "protective," "enclosed," "unattended," and "open" in accordance with NBS Handbook 114. Design criteria will be presented for each of the classes. Safety shall determine the appropriate installation classification for specific radiation-generating devices.

Protective and Enclosed Installations

1. The maximum allowable dose rate at any accessible area 5 cm from the outside surface of the enclosure shall not exceed 0.005 mSv/hr for a protective installation; the enclosed installations must be shielded to limit the maximum allowable dose rate in occupied areas at 30 cm from the outside surface of the enclosure to 10 mrem/h or less and in normally unoccupied areas 30 cm from the outside surface of the enclosure to 1 mSv per hour or less.

2. The dose rate limits shall be based on the operation of the x-ray device at the manufacturer's maximum recommended anode current and excitation potential without added filtration.

3. The single-mode failure concept shall be applied to the design of access ways, warning signals, interlock systems and wherever the potential exists for inadvertent exposure to a radiation field.

4. Entrances into enclosures containing operational x-ray or sealed gamma-ray devices (except those that require tools for opening) shall be provided with an interlock system that will cause the source of radiation to de-energize or return to a shielded position unless the door(s) is closed. For sealed gamma-ray source installations, the shield must cause the dose rate to be reduced to less than 1 mSv per hour. Access should be through a shielded maze.

5. An interlock system shall be designed to be reset only after the controls at the point of interlock trip and at the control console have been reset. The interlock system shall be designed so a single component failure will not jeopardize the safety of the system (e.g., use of series-connected, double-switch assemblies for access doors and dual interlock relays). (National Council for Radiation Protection and Measurement 49)

6. The installation design shall provide the operator means to positively determine that the irradiation area is unoccupied, or an audible or visual warning signal (preferably the rotating beacon type) inside the enclosure shall be activated a minimum of 20s before irradiation begins and the visual signal will remain on during irradiation. Fail ure of the warning signal shall inhibit irradiation. The audible signal shall produce a sound level that can be heard over ambient noise levels. (ANSI N2.3)

7. Emergency exits shall be provided in enclosures designed for personnel access. The exits shall have the capability to be opened from the inside of the enclosure even in the event of a power failure.

8. Emergency power cutoff switches shall be located in the enclosure. The switches should be clearly marked as to their function and should have a manual reset capability. Enough switches should be available so at least one switch is visible from any part of the enclosure and a person can reach a switch within five seconds.

9. The interior of the exposure room shall have a "Danger: High Radiation Area," or "Radiation Area" sign as appropriate, that operates in conjunction with the warning signals. Signs should conform to HSRCM-1, Radiation Control Manual.

10. The entrance to the exposure room shall be posted with a sign containing the radiation symbol and the words "Caution: Entering Radiation Exposure Room." Cabinet-type enclosures containing x-ray or sealed gamma-ray equipment shall have a sign on the outside showing the radiation symbol and "Caution: X-Rays" or "Caution: Radioactive Materials" as appropriate.

Unattended Installations

1. The radioactive source shall be installed in a shielded single-purpose container designed to prevent casual removal of the shielding.

2. Means (e.g., shutter) shall be provided to reduce the intensity of the primary beam. The closed and open positions shall be clearly identified.

3. A steady red light activated by the control circuitry or the radiation level shall be installed near the head and beam port(s) of each device. X-ray machines shall have a visual warning signal activated when x-rays are produced.

4. All beam ports not in use shall be secured in the closed position in a manner to prevent casual opening.

5. Service access doors to radiation areas shall be designed to be opened with special tools.

6. Devices containing radioactive material shall be posted with the radiation symbol and the words "Caution: Radioactive Material"; for an x-ray machine the posting shall include the radiation symbol and the words "Caution: X-Rays."

Open Installation

1. Steady or flashing red lights activated when the device is operational shall be located at the radiation area boundary in sufficient numbers to ensure that at least one red light is visible from each avenue of approach. Postings shall be in accordance with WHC-CM-1-6.

2. Adjacent areas shall be designed as controlled areas.

3. A steady or flashing red light activated by the control circuitry or the radiation level shall be located on or near the source of the radiation.

4. Positive means for preventing access, such as a locked enclosure, shall be provided for periods of unattended irradiation and to prevent unauthorized use of the equipment.

8.3.2 X-RAY DIFFRACTION/FLUORESCENCE ANALYSIS EQUIPMENT

The requirements in this section are divided into general requirements, requirements for open beam x-ray systems, and requirements for enclosed beam x-ray systems. (National Bureau of Standards Handbook 111)

General Requirements

1. The radiation dose generated by components such as the high-voltage supply shall not exceed 0.1 mSv/w at 5 cm from the outside surface of the generator cabinet.

2. The transmitted primary beam shall be shielded so that the dose rate does not exceed 0.0025 mSv/h.

3. A warning light indicating the source of radiation is energized or is in an unshielded position shall be provided near any switch that energizes an x-ray tube. Failure of the warning signal shall cause the source of radiation to de-energize or return to a shielded position.

4. A fail-safe light or indicator shall be located in a conspicuous location near the source housing to indicate when the x-ray tube is energized or the radioactive source port is open.

5. Warning signs shall be provided near the control panel. A sign with the radiation symbol and the words "Caution: This Equipment Produces X-Rays When Energized," or "This Equipment Contains Radioactive Material - To Be Operated Only By Qualified Personnel" or equivalent shall be used.

6. The fail-safe concept shall be applied to the design of access ways, warning signals, interlock systems, and whenever the potential exists for inadvertent exposure to a radiation field.

Requirements for Open Beam X-Ray System

1. All shutters shall be provided with an indication that the shutter is open. Failure of this component shall cause the source of radiation to de-energize.

2. The maximum permissible dose rate 5 cm from the exterior or the x-ray tube housing with all shutters closed and the equipment operating at full-rated power and maximum accelerating potential shall be equal to or less than 0.025 mSv/h.

3. Each port of the radiation source housing shall be provided with a beam shutter interlocked with the x-ray coupling or collimator that will allow the port to open only when the coupling or collimator is in place. Shutters at unused ports shall be secured to prevent casual opening.

4. Means should be provided to prevent any part of the body from being exposed to the primary beam.

Requirements for Enclosed Beam X-Ray System

1. The radiation source, sample, and detector(s) shall be enclosed in a chamber or chambers that cannot be entered during normal operations.

2. Shielding shall be provided so that the dose rate 5 cm from the outer surface does not exceed 0.0025 mSv/h during normal operation.

3. The sample chamber closure shall be interlocked with the x-ray tube high-voltage supply or a shutter to ensure no radiation enters the sample chamber while the access panel is open. Failure of the interlock shall cause the source of radiation to de-energize.

4. All ports shall have a beam shutter interlocked with a collimator or coupling that only allows the shutter to open when the coupling or collimator is in place. Shutters at the unused ports shall be secured against casual opening.

8.3.3 PARTICLE ACCELERATORS

1. The design of safety systems (e.g., interlocks, warning signals, monitoring devices) shall be based on the fail-safe principle. Maximum reliance should be placed on passive components (e.g., walls, locks) rather than active components (e.g., warning signals, radiation monitoring systems).

2. Primary controls for the generation of radiation shall be designed to be secured against unauthorized use.

3. An interlock system shall be completely reset after the controls at the point where the interlock tripped and the control console have both been reset.

4. All entrances into a target room or restricted access area shall have interlocks that cause the accelerator to shut down when tripped.

5. Emergency power cutoff switches shall be provided in high-radiation and restricted access areas. Enough switches should be available so at least one switch can be seen from any location in the area and a person can reach a switch within 5 seconds. The switch shall have positive identification and have a manual reset capability.

6. All locations designated as radiation areas, high-radiation areas, restricted access areas, and entrances to such locations shall be equipped with easily observable flashing or rotating purple warning lights (ANSI Z53.1) that operate automatically only when radiation is being produced. Lights of a different color shall be used for other required visual indicators (ANSI Z53.1). Redundancy shall be built into the system such that an alarm will sound or irradiation will terminate if the warning light malfunctions during radiation production.

7. Audible warnings shall be given before startup of the accelerator. Horns, Public Address system, or buzzers shall be located in areas with emergency power cutoff switches. The audible warning should be long enough for a person's attention to be attracted above the ambient noise level and for the person to have enough time to exit or reach an emergency power cutoff switch. The audible warning signal shall be tied to the interlock system to prevent irradiation while the signal is activated.

8. Shielding requirements shall be based on continuous accelerator operation at maximum output for a 40-hour week.

9. Movable radiation shielding that supplements the accelerator facility shielding shall be provided with interlock switches that prevent irradiation unless the shielding is properly positioned.

10. Ventilation requirements for accelerator installations operating at or above 10 MeV may need to provide for the removal of ozone, NO_x, and/or radioactive gases.

11. The number of personnel access portals into high radiation areas should be minimized.

12. The interlock system should be designed to readily identify the specific interlock that activates an alarm signal.

13. The safety interlocks and the warning device, intertied with the radiation control circuitry, should not be dependent on a single circuit.

9.0 SAMPLING AND MONITORING

9.1 AIR SAMPLING AND MONITORING

9.1.1 INTRODUCTION

There are four main reasons for collecting air samples; to measure breathing zone airborne contamination levels, to detect failures in containment devices, and to warn personnel of airborne contamination that exceeds control limits.

Air samples to confirm the absence of airborne contamination may be taken at the room air exhaust or other suitable location that indicates the general condition within the room. These samples usually cannot indicate where, or when, air contamination occurred. Air samples to measure airborne contamination levels are usually related to a specific job or work site, or to airborne radioactivity being released to the environment through stacks or vents. Air samples should be collected from the breathing zone of the workers since the emphasis should be on air samples representative of what was breathed by workers. Air samples to detect failures in containment systems are usually associated with a specific containment enclosure. Duct air samples fall into this category since they may indicate failure of an exhaust air cleaning device such as a HEPA filter. The CAMs provide warning of significant airborne contamination and are usually associated with work sites or stack exhausts.

9.1.2 GENERAL CONSIDERATIONS

1. Health Physics shall approve the number, type, and location of air samplers and monitors.

2. Air sample heads and probes shall face upstream into the expected direction of air flow.

3. Collecting filters should be oriented in a vertical plane (unless the direction of air flow dictates a different orientation) and supported with a porous backing free of sharp edges and burrs.

4. Whenever possible and reasonable, the collecting filter shall be located in the air stream to be sampled rather than diverting a portion of the air stream to the collecting filter.

5. Air sample heads shall be located at, or lower than, five and one-half feet above the floor on a platform provided to aide in changing the filter.

6. Air sample heads shall not be located where they would cause a safety problem or otherwise interfere with the performance of work.

7. Sample heads should be detachable for ease of maintenance and decontamination.

8. For particulate sampling, a compression sealing ring designed to press the perimeter of the filter against the backing support should be provided to ensure an airtight seal.

9. Each sample head should be equipped with a flow-rate indicator and regulator located downstream of the collecting filter. (DOE/EV/1830-T5)

10. Sample vacuum lines should be designed to be as short and bend frre as possible.

11. Airborne radioactivity should be sampled in accordance with HSRCM-1 Radiation Control Manual.

Important Application Notice

To ensure that current investigative information is used to develop designs, the following special notice is given for the use of all designers and users of this design guide:

The Health Physics Radiological Engineering group characterizes particle size distributions in WHC facilities. Respirable particles (0.1 to 10 micron aerodynamic equivalent diameter) are evaluated for chemical radioisotopic composition. The information obtained from these studies, combined with recent technological advances in aerosol physics, will permit improvements in the design of airborne contamination monitoring and sampling equipment (including samplers, sample transport lines, and filtering equipment).

Many requirements in this section are generic and apply to circumstances for which no information about the airborne contaminants present is available. The requirements of this design guide will be modified to reflect the best available state of technology when Health Physics completes the particle size and composition studies,. (Basis: ANSI N13.1-1969, Sections 4.2.2.1 and 5.2.2; ICRP 30; Reference "Estimation of Line Loss in Westinghouse Hanford Company Work Place Air Sampling and Monitoring Systems," 33160-90-JPG-014.)

Before beginning any sampling and monitoring systems design, the design engineer shall contact the Radiological Engineering section of Health Physics to establish specific criteria for the design. These criteria shall be approved by Health Physics.

9.1.3 BREATHING ZONE SAMPLING TO MEASURE AIRBORNE CONTAMINATION LEVEL

1. Wherever a worker is likely to receive, under normal conditions, an annual intake of 2 percent of the annual limit of intake, a sample shall be collected which is representative of the worker's breathing zone. (ANSI N13.1)

2. Sufficient pump capacity should be provided to maintain a minimum flow of 2 cfm through each sample head under all normal and anticipated abnormal conditions. (DOE/EV/1830-T5.) A dedicated central vacuum system that provides a pressure difference of 20-inch mercury with all units operating is preferred over individual pumps.

3. Redundant pumps should be provided and each pump should have a 15 percent reserve displacement capacity. (DOE/EV/1830-T5)

4. A low-flow alarm system with annunciation in a frequently or continuously occupied area should be provided.

5. Automatic back-up power should be supplied and it should be independent of the normal power supply.

6. Provisions should be made to allow for periodic flushing of the system to minimize contamination buildup.

9.1.5 AIR SAMPLES TO DETECT CONTAINMENT SYSTEM FAILURE

1. Deterioration in contamination control barriers shall be monitored near hot cells, gloveboxes, and open-faced hoods where significant quantities of dispersible radioactive material are handled.

2. The air sample head shall be located where detection of failure is maximized even if this location is outside the breathing zone.

3. Duct air samples shall be taken downstream of each HEPA filter or other air cleaning device.

4. Given a choice of where to locate the air sampling head when collecting a duct sample, the sample port closest to the potential source (usually a HEPA filter) shall be chosen.

9.1.6 WARNING OF SIGNIFICANT AIRBORNE CONTAMINATION

1. Continuous air monitoring shall be provided in areas where the airborne concentrations are expected to exceed a deriver air concentration (DAC).

2. Continuous air monitors should be capable of measuring eight DAC-hours.

3. Audible and visual signals shall be provided locally for the high radiation alarm. A remote alarm should annunciate in an area of continuous or frequent occupancy. The local visual and the remote alarms should remain energized until the cause of the alarm is removed.

4. Alarms shall be provided for instrument failure and loss of power. These alarms shall be separate from the high radiation alarm.

9.2 AREA RADIATION MONITORING SYSTEMS

1. Health Physics shall approve the number, type, and location of area monitors.

2. Area monitors should be provided in frequently occupied locations with the potential for unexpected increases in dose rate and in remote locations where there is a need for local indication of dose rates prior to personnal entery.

3. Local and remote alarms shall be provided for instrument failure and high radiation. The failure alarm(s) shall be separate from the high radiation alarm.

4. Automatic back-up power should be provided and the instrumentation shall be capable of returning to normal operation following switching transients.

5. The instrument response to radiation levels in excess of the maximum instrument range (up to ten times) shall be to indicate the full-scale value and remain upscale until the source of radiation is removed. After the source is removed, the reading should return to ambient levels within one minute. (ANSI N320)

6. The design should minimize the effects of voltage transients on the system (e.g., through the use of voltage regulators, stabilizers).

7. Alarm signals should be transmitted to a remote location that is frequently or continuously occupied.

8. Real-time data should be transmitted to a remote location that is frequently or continuously occupied.

9. Radiation detector assemblies, electronic modules, readout and display devices, and power supplies should be interchangeable and have in-place calibration and functional testing capability.

10. The area monitor ranges should overlap the ranges of the emergency instrumentation. (ANSI N320)

9.3 AIR EFFLUENT SAMPLING AND MONITORING

9.3.1 GENERAL CONSIDERATIONS

1. Safety shall approve the number, type, and location of effluent samplers and monitors.

2. Sampling and monitoring systems shall be designed to take a representative sample of the effluent stream.

3. Sampling and monitoring systems should be placed downstream of the effluent treatment system and as near to the environmental discharge point as practical.

4. Airborne effluent systems shall be sampled as required by WHC-CM-7-5, Environmental Compliance.

5. The system shall be able to function properly in the chemical environment of the exhaust. The exhaust stream shall be characterized (e.g., flow rate and chemical composition) before design.

6. The sample probe should be at least two, but preferably five, or more duct diameters or major duct dimensions downstream of any flow perturbation, e.g., elbows, bends, junctions, and reduction. It should also be located at least two duct diameters upstream of any major flow disturbance.

7. Sample probe design and location should be based on flow profile information at the point of sample extraction to ensure representative sampling. Probes should be spaced so as to intercept approximately equal rates of flow.

8. Nozzles should have tapered knife edges (30° taper - outside edge of orifice) and face directly into the exhaust stream.

9. Each nozzle bend should have a radius of greater than, or equal to, five times the orifice diameter.

10. Nozzles should be sized to provide isokinetic extraction.

11. Nesting (placed close together) of CAM system probes and sampling probes is preferred.

Transport Lines

1. Tubing size should be selected to minimize particle deposition due to gravitational settling and/or impaction.

2. The transport line should be fabricated of material that is not reactive to the effluent or conducive to electrostatic deposition.

3. Total length of the lines between the sampling probes and filter holders should be as short as practical.

4. Horizontal runs should be minimized.

5. The number and angle of bends should be minimized. Bends should have a radius of at least ten times the inside diameter of the transport line. The sum of the bends should be less than 110°.

6. Use of pipe or tubing fittings between the sample probe and filter holder should be minimized.

7. Condensation shall be minimized. Thermostatically-controlled electrical heat tracing shall be used on transport lines where condensation is a potential problem. The sample transport lines shall be insulated.

8. If economically and technically feasible, each CAM should have a separate sampling probe. A sharp-edged flow splitter should be used to evenly divide the sample stream if one probe must serve multiple monitoring units. The flow splitter should divide the stream near-isokinetically.

9. The air movement system shall be powered from a source which has the same backup capabilities as the air mover for the stream being monitored. If the emergency backup capability for the stream being monitored is from a nonelectrical source, it is then necessary to provide backup electrical power for the air movement system.

10. All systems should be served with a vacuum system capable of providing a minimum negative pressure of 20-inch mercury when all units are in simultaneous use.

11. Central vacuum systems should have (a) 2 pumps of sufficient capacity to permit uninterrupted vacuum conditions in the event 1 pump is out of service, and (b) sufficient pump capacity to provide a negative pressure of 20-inch mercury when all units are in use plus a reserve capacity of 15 percent or more.

12. The vacuum should be locally adjustable for each system. Vacuum systems for record samplers shall operate whenever, and only if air is being exhausted from the duct or stack.

13. The vacuum system should have the means of providing a near constant flow rate with audible and visual alarms to indicate a loss of air flow locally and in an area subject to continuous or frequent occupancy.

14. The air-flow measuring devices should have a range suitable for anticipated flow rates.

15. The exhaust stream from the vacuum system should be vented to effluent streams which are monitored for the requisite pollutants and noxious gases. Exhaust streams from outdoor installations which meet the requirements of WHC-CM-7-5, Environmental Compliance, may be exhausted directly to the atmosphere.

16. The average record sample flow rate should be at least 2.0 cfm. The air through the CAM should not exceed 3 cfm and the vacuum source should be no greater than 6 inches of mercury.

9.3.2 EFFLUENT SAMPLING SYSTEMS

1. Sampling for particulates will almost always be appropriate. The need for sampling gases or semi-volatiles shall be assessed.

2. The particulate sample filter holder should be located as close as practical to the probe.

3. The particulate sample filter holder should have tapered expansion and contraction cones upstream and downstream of the sample filter.

4. The particulate filter holder should have a permanently mounted porous filter-backing free of sharp edges and protrusions.

5. The particulate filter holder should have a compression sealing ring designed to provide an airtight seal around the filter paper.

6. The sample filter holder should be easily opened and closed.

7. The sample filter holder should be fabricated of materials that are neither reactive to the effluent nor conducive to electrostatic deposition.

8. Sampling systems for stacks that operate intermittently shall include a clock to provide an indication of accumulated stack operating time.

9. Measurements of sample flow rate and total flow shall be made. The flow rate meters and flow volume totalizers should be located downstream of the sample collection point.

9.3.3 EFFLUENT MONITORING SYSTEMS

1. Monitoring and alarm systems shall be provided for airborne effluents that have the potential to exceed ten percent of any DAC value on an annual average, as noted in Appendix C, WHC-CM-7-5, Environmental Compliance.

2. There should be indicators for (a) the air flow through the monitor; (b) the operational status of all counting equipment; and (c) operational status of the sample vacuum systems.

3. Audible and visible high-level release alarm and CAM system failure indicators should be placed as required. Each of these alarms should be capable of alarming locally and in an area subject to frequent or continuous occupancy by operations personnel. These alarms should

be independent of each other (i.e., a high-level release alarm should not also be used as a failure alarm).

4. Provisions should be made to record the relative levels of effluents sensed either electronically or electromechanically (e.g., a strip chart recorder). In addition, there should be the capability of transmitting data to a remote location.

5. All CAM systems that monitor effluents from enclosed systems (hot cells and gloveboxes) or semi-enclosed systems (fume hoods) should be provided with an indicator panel which provides readout, annunciation, recording, and alarm indications. This indicator panel should be located such that the operator of the enclosed or semi-enclosed system can monitor it from the normal work stations.

6. Circuitry or shielding should be provided to mitigate the effects of noneffluent contributions (e.g., background), as well as extraneous contributions from the effluent. If this mitigation is accomplished by electronic means (e.g., background subtraction), then the effectiveness of this mitigation must be verified during calibration.

7. The design should minimize the effects of voltage transients through the use of voltage regulators or stabilizers.

9.4 LIQUID EFFLUENT SAMPLING AND MONITORING SYSTEMS

9.4.1 Sampling Systems

1. Sampling systems shall be provided for all liquid effluents that have a potential for exceeding concentrations equivalent to the Drinking Water Standards contained in 40 CFR 141.

2. Sampling systems shall be designed to take a representative sample of the effluent stream. The sample location shall be as close to the environmental discharge point as practical and downstream of the effluent control systems.

3. Automatic samplers should operate on a flow proportional basis as controlled by a flow measurement system. The flow-metering device should be equipped with a flow totalizer for recording total effluent volume released from a given source.

4. Sampling probes should be suspended in the water so as not to pick up particulate matter from the bottom or top of the stream, pond, or basin.

5. The sampler should have a sufficiently high transport velocity to ensure accurate collection and transport of suspended solids to the sample collector. Lengths of sample tubing should be minimized.

6. The sampling system should ensure that no unsampled releases occur due to power failure (the sampler shall have back-up power).

7. The sampler should be equipped to minimize cross-contamination by sample line flushing or other methods.

8. For a batch discharge system, mechanical mixing or other design should ensure reasonable homogeneity of a batch prior to sampling. The system should have the means for accurate determination of batch volumes to permit volume-weighted compositing of grab (taken at random as opposed to continuous) samples.

9.4.2 Monitoring and Diversion Systems

1. Monitoring systems shall be provided for all discharged liquid effluents that have the potential of exceeding four times the applicable administrative control limits in WHC-CM-7-5.

2. Monitoring shall be provided for each radionuclide which has the potential for exceeding the values in (9) above unless an increase in one radionuclide concentration is accompanied by proportional increases in another type.

3. Monitoring systems should be placed upstream from diversion systems and downstream of effluent treatment systems.

4. Monitors should have distinguishable, audible, and visible high radiation alarms capable of alarming in an area subject to frequent or continuous occupancy.

5. Monitors should have distinguishable, audible, and visible detector failure alarms capable of alarming in an area subject to frequent or continuous occupancy.

6. Monitors should have distinguishable, audible, and visible loss-of-sample alarms capable of alarming in an area subject to frequent or continuous occupancy.

7. Monitors should have distinguishable capability to transmit a real-time measurement to a remote location.

8. Accessibility and maintainability should be considered with respect to the system configuration to accommodate inplace calibration and maintenance.

9. A diversion and retention system shall be coupled with the monitoring system if the potential exists for exceeding the limits contained in WHC-CM-7-5.

10. Retention capacity shall be sufficient to retain the volume of liquid which exceeds the applicable limits based on a safety analysis postulated upset. The retention basin should be covered.

9.5 CRITICALITY ALARM SYSTEMS

Design criteria for criticality alarm systems is covered in WHC-CM-4-29, Nuclear Criticality Safety.

9.6 PERSONNEL CONTAMINATION MONITORS

1. Health Physics shall approve the types, numbers, and locations of the monitors.

2. The design shall include types, numbers, and locations to meet the requirements of the Radiological Control Manual.

10.0 WASTE HANDLING, STORAGE, AND DISPOSAL

10.1 INTRODUCTION

Radioactive wastes, both solid and liquid, are generated during operations in many nuclear facilities. The quantity, concentration, and nuclide mix are dependent upon the types of operations performed within the facility. Waste handling, storage, and disposal design criteria are based upon requirements dictated by the projected usage of the facility. Application of these criteria will ensure:

1. Reliable operation of waste disposal systems
2. No release of radioactive materials above established limits to the environment from operation of waste disposal systems
3. Radiation exposure to operating and maintenance personnel is maintained ALARA.
4. Capabilities exist for routine maintenance and testing of the system for proper operation.

10.2 SOLID RADIOACTIVE WASTE HANDLING AND STORAGE

1. Separate areas should be built for waste handling and waste storage. The areas should be compartmentalized to the extent practical and they should be sited as close to existing sites as possible.
2. The waste handling and storage areas should be located to allow access without traversing routine traffic areas or uncontrolled areas. (DOE-EV-1830-T5)
3. Provisions for sorting the waste according to dose rate, half-life, and compactability should be provided.
4. The storage area for solid waste should be designed for a minimum capacity of twice the maximum anticipated waste volume generated between disposals. (DOE-EV-1830-T5)
5. Fire protection must include one or more of the features listed under "Fire Protection Methods" in Chapter X of DOE Order 6430.1.

10.3 SOLID WASTE DISPOSAL

1. Solid low-level waste generated by DOE operations must be disposed of at DOE shallow-land-burial or greater-confinement disposal sites. (DOE Order 5820.2)
2. The land area for nonretrievable solid radioactive waste must be as small as technically and economically practical. (Implementation plan DOE-RL Order 5820.2)
3. Radioactive solid waste burial grounds shall be located within the 200 Area (WHC-CM-7-5, Environmental Compliance) and contiguous to existing waste disposal sites.

4. Disposal sites shall be permanently marked and the markers shall meet the requirements of Hanford Standard AC-5-40.

5. Provisions must be made to allow intact contamination-free retrieval and identification of transuranic waste with concentrations greater than 3700 Bg (10^{-7} curies) per gram of waste matrix for up to 20 years after emplacement. To the extent technically and economically practical, all transuranic waste shall conform to the Waste Isolation Pilot Plant--Waste Acceptance Criteria. (Implementation plan for DOE Order 5820.2)

6. The following considerations from DOE Order 5820.2 should be addressed during disposal site design:

   - Measures for reducing wind and water erosion and other effects of surface water runoff, efficient land use, enhancement of the natural physical characteristics of the area, long-term isolation of the waste, and minimizing the need for active maintenance or remedial action.

   - Environmental monitoring, fire suppression, utility and security systems; disposal and buffer zone areas; administrative, decontamination and maintenance facilities; access to road and rail systems; and formal emergency plans.

   - Waste handling and treatment facility(ies) located and designed for ease of waste handling and minimizing the potential for human exposure and contamination spread.

   - A grid system for locating all disposal excavations on a site map which is referenced to U.S. Geological Survey or National Geodetic Survey benchmarks.

   - Disposal excavations designed and constructed consistent with site hydrology, geology, and waste characteristics, and having excavation covers which provide for effective isolation of the waste.

10.4 LIQUID RADIOACTIVE WASTE SYSTEMS

10.4.1 GENERAL CONSIDERATIONS

1. The liquid waste system, including components and required supporting services, should be capable of handling the expected volume of potentially radioactive waste generated (1) during normal plant operations and (2) under credible conditions postulated by a technical evaluation. This evaluation shall be performed as part of the design effort.

2. The system design should provide for redundancy or diversity of components to meet reliability requirements.

3. All components of the liquid waste system should be designed for safe shutdown during normal operation or under emergency conditions to prevent release of hazardous or radioactive material to the environment.

4. Provisions for backup power should be included for process components as determined by a safety analysis.

5. Tank and piping systems used for liquid waste handling, treatment, and storage should be of welded construction to the fullest extent practicable.

6. Tank and piping systems used for liquid waste handling and treatment should be designed to take advantage of gravity flow to reduce the potential for contamination associated with pumping and pressurization. Contaminated systems should be separated from "clean" systems. Backflow preventers shall be required at all interfaces between hazardous and "clean" systems.

7. The area in which liquid radioactive waste is treated should be isolated from production, loading, storage, and support facilities by compartmentalization and access controls to reduce the potential for cross contamination.

8. The design of the liquid radioactive waste system shall ensure that accidental criticality will not occur under normal operating conditions or under any credible accident condition. This design shall incorporate the double- or triple-contingency policy referenced in WHC-CM-4-29, Nuclear Criticality Safety Manual.

9. Potentially radioactive effluent waste streams shall not be used for disposal of hazardous chemicals.

10. Provisions shall be made for the direct visual inspection of piping wherever possible. Buried, or otherwise inaccessible piping, shall be pipe-within-a-pipe. The inner pipe is the primary boundary; the outer pipe (encasement) forms the secondary boundary.

11. The systems shall be capable of handling liquid waste with the following characteristics:

    - Temperatures - 50°F to 180°F

    - Radioactivity - Alpha, beta, and gamma emitters in total concentrations up to
      maximum expected

    - pH - 0.1 (strongly acidic) to 13.0 (strongly basic)

    - Dissolved salts from a variety of chemical reactions.

12. The operating service life of system components shall be at least 25 years, during which time they shall perform their intended functions within the tolerances and environmental conditions specified herein without failure or maintenance.

13. The piping shall be sized to handle 150 percent of maximum design liquid waste flow rate. Flow rates in the trunk line, downstream of the new branch, shall be reviewed to ensure there is adequate capacity to handle the influent from the proposed addition as well as existing contributing lines.

14. Drains from cells, gloveboxes, or hoods where radioactive particulate materials (such as powders or grindings) are present shall have installed filters that remove particles larger than 250 microns. Other access points shall have suitable screens or filters installed.

15. Pressurized piping shall be designed for an initial hydrostatic test of 150 percent of design pressure and subsequent annual hydrostatic testing at 110 percent of operating pressure.

10.4.2 COLLECTION SYSTEM

1. Materials used in the liquid waste collection system shall be capable of safely handling waste to be collected. All components of the system expected to be in contact with strong acids or caustics should be corrosion resistant (e.g., lined with suitable synthetic resin materials or made of stainless steel that is not reactive with the wastes).

2. Drain systems for storm water and sanitary sewage should be separate from contaminated waste drain systems.

3. Individual lines should be used for each waste stream fed to the central collection tank(s) where necessary to prevent chemical reaction or introduction of contaminants such as complexing agents which could interfere with waste decontamination and to permit determination of flows and monitoring of waste streams from each source area.*

4. The use of traps in radioactive liquid waste lines should be avoided and the piping should be designed to minimize entrapment and buildup of solids in the system.

5. Measurement capability should be provided to determine the volume and radioactivity of wastes fed to the collection tank(s). The measurement devices should be provided with recorders, indicators, and alarms.

6. Waste collection system pipes and drain lines should be tagged, labeled, or painted in a manner that permits easy identification.

7. Bypasses that would permit waste streams to be routed around collection tank(s) should be avoided.

8. The collection system shall provide tanks, valving, pumps, and piping for accumulation, storage, sampling, mixing, and loadout of liquid waste.

9. The collection system shall provide the capability for adding chemicals to the liquid waste during storage and prior to transfer to the disposal system.

10.4.3 PIPING

1. Cleanout connections, sized to match the pipe, shall be provided at 90° pipe corners of all underground primary piping for use in flushing and cleaning operations.

2. Encasement (secondary containment) piping shall have connections to introduce dry air or nitrogen for pneumatic pressure tests.

3. Valves and valve pits shall be provided at 90° pipe corners of all underground piping for use in flushing and cleaning operations.

4. All piping connections shall be welded except for cleanout closures and valve bodies which shall be flanged.

5. Valves shall be full port valves whose bore matches the internal diameter of connected lines.

6. Drain valves shall be provided at low points of all sections of system piping. Vent valves shall be provided for those sections that will not drain freely.

7. Taps for instrumentation, test connections, and similar small diameter pipe shall be made on the top of the pipe.

8. Deadlegs and low-flow areas of piping shall be minimized.

9. Piping which is gravity drained shall be installed with a slope which results in a liquid velocity of at least 2 fps at the average rate of flow.

10. Piping outside of facilities shall be located beneath all other piping and electrical cables.

11. All piping shall be of welded construction wherever possible. One-hundred percent radiography and/or dye penetrant shall be employed to verify the integrity of these welds.

12. When pipe-within-a-pipe containment is used, the outer pipe shall be designed to withstand system pressure.

13. Hydrostatic test connections shall be provided for piping that is not pipe-within-a-pipe.

14. All flanged joints shall have catch pans installed. Flanged joints shall not be used for any buried connection. When flanged joints are utilized in areas where catch pans cannot be visually inspected periodically, suitable leakage detection devices shall be employed.

15. For highly contaminated piping runs in areas where personnel access is necessary, piping hangers and piping shall be designed and sized such that up to one inch of lead shielding could be installed without requiring the addition or replacement of hangers.

16. Decontamination taps shall be provided for piping runs where a buildup of radioactive materials cannot be prevented or avoided.

17. Where remotely operated valves are provided, control panel indication of both open and closed positions shall be provided.

10.4.4 LIQUID WASTE LOADOUT STATIONS

1. Loadout station couplings shall match tank cars used by WHC. Coupling design shall permit rapid coupling and decoupling with minimum spillage.

2. Process water shall be available at the loadout station. Backflow preventers shall be provided on process water systems. Steam systems for decontamination should be provided at the loadout station.

3. The loadout station shall have sloped and painted floors, caulked joints, and shall slope to a sump which returns drainage to the collection tanks via a drain line that has a secondary containment.

4. Collection tank(s) shall be sized to hold at least a 15-day volume at design flows.

5. When multiple collection or storage tanks are used, a provision shall be made for individual selection of such tanks.

6. Collection and storage tanks shall be maintained at a pressure more negative than the tank enclosure atmosphere. The value of the pressure differential shall be $\geq$0.25 inches of water.

7. The tank enclosure, when provided, shall be equipped with exhaust ventilation capable of maintaining the enclosure atmosphere at a pressure that is negative relative to local atmospheric pressure. The value of the pressure differential shall be $\geq$0.05 inches of water.

8. Provisions shall be made to agitate the contents of collection and storage tanks.

9. Provisions shall be made for sampling tank contents.

10. Facilities or vaults that contain liquid waste storage tanks shall have a means of containing, without leakage to the environment, the volume of the tanks in the event they leak catastrophically. Bare concrete is not sufficient to ensure such containment. If concrete is used for this containment, all concrete joints shall be caulked, and the concrete shall be sealed with a material compatible with the chemical composition of the liquid wastes. The use of sumps, curbs, and similar devices is encouraged to contain the wastes to the smallest possible area.

11. The tank enclosure, when provided, shall be capable of decontamination.

12. Remote alarming liquid detection devices shall be installed in the tank enclosure low point.

13. All piping and instrumentation taps shall enter the top of the liquid waste storage tank(s).

14. Tanks that may be pressurized shall be provided with relief valves or rupture discs for over-pressure protection. Any gases discharged shall be suitably filtered, and any liquids discharged shall be suitably contained.

15. Tank overflows may be interconnected among various tanks; however, an overflow line with unimpeded access shall be provided from one of the tanks to a controlled sump in which a liquid alarm is provided.

16. Tanks shall be provided with two independent means of liquid level determination. These systems shall be designed such that an incremental increase or decrease of not more than 100 gallons or ten percent of usable tank volume (whichever is less) can be detected. For larger volume tanks, the best available technology is recommended for liquid level determination.

17. Tanks shall be provided with vacuum protection devices if not rated for full vacuum.

10.4.5 VALVE AND CLEANOUT PITS

1. Valve and cleanout pits shall have coatings to ensure integrity of containment and ease of decontamination. Access penetrations shall be sealed to provide containment.

2. Valve pit sumps shall have installed leak detectors.

10.4.6 INSTRUMENTATION AND CONTROL

1. Human Factors Engineering (see Appendix A) principles shall be employed in the design and layout of control panels.

2. Radiation monitors shall be provided at the tank car loadout station, at the liquid waste system inlet to the collection tank enclosure, and at other normally accessible locations that are subject to rapid changes in radiation levels.

3. Monitors shall be provided to determine the beta-gamma, radioiodine and alpha content, as appropriate, of the ventilation exhaust streams issuing from the collection tanks and the collection tank enclosure.

4. A diverter station, consisting of a radiation monitor and a flow-directing valve that is operated by signals from the radiation monitor at predetermined radionuclide concentrations, shall be installed to route potentially contaminated water to the liquid waste system when the radionuclide concentration exceeds 7.4 Bg (5×10^{-5} uCi) per mL.

10.4.7 ANNUNCIATION

Remote annunciation shall be provided at a continuously monitored control station, if provided, for the following parameters:

- o High area radiation
- o High liquid waste radiation
- o High beta-gamma, radioiodine or alpha in the collection tank and tank enclosure air exhaust streams
- o Liquid leaks
- o High sump levels
- o High tank and basin levels
- o Diversion.

10.4.8 MAINTENANCE

1. Access shall be provided for personnel, tools, and handling equipment.

2. The ventilation system shall be capable of maintaining loadout and storage facility ambient temperatures greater than freezing in winter and less than 100°F in summer.

3. Electrical components and components with moving or replaceable parts shall be capable of being tested, calibrated, adjusted, and certified (or recertified) for operation following maintenance.

10.4.9 SURVEILLANCE AND INSPECTION

Provision shall be made for testing of piping that cannot be accessed for direct visual inspection.

10.4.10 SAMPLING STATIONS

1. Sampling shall be performed in a hood that provides adequate ventilation and filtration.

2. Sampling station piping shall be designed to:

    - Minimize dose rate in the work area
    - Provide shielding, as required, to ensure a low dose rate work area
    - Provide representative samples by minimizing deadlegs.

3. An area radiation monitor should be provided.

4. Sampling station valves should be readily accessible and shall be labeled as to function. The final sample valve shall be a "dead-man" style valve.

5. The sampling station shall be:

    - Constructed of materials that are easily decontaminated
    - Located in an area in which personnel access is easily controlled
    - Isolated from other equipment and operations.

6. Sample station drain shall be routed to the liquid waste system tank(s).

7. Consideration should be given to processing and storage capacity for unusual or emergency situations. The capability for intertank transfers should be provided. Generally, the minimum sufficient capacity of a liquid waste storage system tank is that required to store waste generated during twice the maximum period anticipated for radioanalysis and discharge of the largest storage tank in the system.

8. At least two storage tanks for treated liquid waste should be provided. Tankage should be fitted with a liquid-level indicator, equipped so that leaks may be detected, and located within a shielded cell with recycle capability to the tanks or alternative storage.

9. Agitators or other means of circulation capable of mixing the contents shall be installed on storage tanks so that representative samples of liquid waste from each tank may be obtained.

10. Provisions should be made to permit recycle of liquid waste from storage tanks to holdup tanks.

11. Provisions should be made so that liquids to be transferred to or from a storage tank can be representatively sampled before transfer.

12. The vessel ventilation system shall be designed to meet the requirements contained in Section 4.0 pertaining to effluent treatment.

10.7 LIQUID WASTE SITES

1. All waste handling, transfer, and storage facilities must be double contained. (DOE Order 5820.2)

2. The tanks shall be located below grade to utilize the shielding properties of the soil.

3. Leak detection capability must be provided (DOE Order 5820.2). Monitoring shall be provided between the primary and secondary confinement barriers and for detecting leakage into the soil. (DOE/TIC-11603)

4. Tanks and piping systems used for liquid HLW collection, treatment, and storage should be of welded construction to the fullest extent practicable. (DOE/TIC-11603)

5. Agitation capability for the tanks should be provided. (DOE/TIC-11603)

6. Spare pipelines shall be installed between transfer points for liquids. (DOE Order 5820.2)

7. The ventilation system shall meet the requirements contained in Section 4 of this design guide.

8. The ventilation system shall be sized to prevent the over-pressurization of the tank due to thermal expansion during normal and anticipated upset conditions. (DOE/TIC-11603)

9. The design of the ventilation system shall prevent the accumulation of hydrogen from reaching a four percent by volume concentration.

10. The design should provide the means to transfer waste which has leaked into the annular space between the primary and secondary barriers to a nonleaking tank. (DOE/TIC-11603)

11. Liquids should be contained in a manner that will allow for removal and transfer of 95 percent of the tanks capacity. (DOE Order 5820.2 and DOE/EIS-0013, Vol. 2)

12. Spare capacity, sufficient to contain the volume of any tank, shall be provided for in each tank farm. (DOE Order 5820.2)

13. Cooling systems should be designed at a positive pressure with respect to the waste, capable of providing adequate cooling under upset conditions; and detect and control waste leakage into the coolant or coolant leakage into the waste.

ACRONYMS

ALARA	As Low As Reasonably Achievable
ANSI	American National Standards Institute
ASHRAE	American Society of Heating, Refrigerating and Air Conditioning Engineers
ASME	American Society of Mechanical Engineers
CAM	Continuous Air Monitor
CFM	Cubic Feet per Minute
DAC	Derived Air Concentration
DBA	Design Basis Accident
DOE	US Department of Energy
FPM	Feet per Minute
HEPA	High Efficiency Particulate Air
HLW	High Level Waste
IAEA	International Atomic Energy Agency
ICRP	International Commission on Radiological Protection
SAR	Safety Analysis Report
WHC	Westinghouse Hanford Company

GLOSSARY

Access Ports - Openings with covers or seals which provide a means of introducing and in some cases removing material or equipment from the glovebox without jeopardizing pressure differentials, atmosphere purity, or contamination control. Such ports include bag ports, sphincter seals, airlocks, and canister ports.

Airlock - A chamber attached to a glovebox having two doors, one opening into the glovebox and one opening into the room where the glovebox is located. An airlock is used for transferring materials and equipment into the glovebox without directly opening the contaminated space to the room atmosphere. Airlock is used to describe an enclosed vestibule, a chamber between different ventilation zones accessible to personnel entering or leaving the space. Airlocks provide barriers to the spread of contamination and reduce unacceptably high airflow rates between the

ventilation areas. Doors have annunciators so that only one door is opened at a time to provide a better degree of isolation.

Anthropometry - The science dealing with measurements of the human body to determine physical differences in individuals and groups.

Bag Port - An opening for introducing and removing items from a contam-inated enclosure. The port uses plastic bagging material to prevent the spread of contamination or opening of the contaminated space to the atmosphere.

Basement - A level underneath the working area of a glovebox but within the glovebox structure that is used for storage. It generally has three solid sides with bag and glove ports on the fourth side.

Canister Port - A special port with a circular hinged door which rotates to lock and unlock. A special canister, with a mating cover, can be attached to the port by rotating and locking it in place. When the canister port door is opened by rotation, it locks to the canister lid and removes it, opening the canister directly to the interior of the glovebox.

Contamination - Radioactive material in any place where it is not desired, particularly where its presence may be harmful.

Controlled Area - Any area to which access is controlled in order to protect individuals from exposure to radiation and radioactive material.

Decommissioning - Removal from service with measures taken to protect people, property, and the environment from contamination and exposure.

Decontamination - The reduction or removal of contaminating radioactive material from a structure, area, object, or person.

Derived Air Concentration - The concentration of a radionuclide in air which, under conditions of continuous exposure by one exposure mode (i.e. inhalation of air), for one year, a "reference man" would receive the most restrictive of: (1) an effective dose equivalent of 1 mSv (100 mrem), or (2) a dose equivalent of 50 mSv (5 rem) to any tissue, including skin and lens of the eye.

Dispersible Materials - Material which may become airborne or can be spread about. This includes radioactive materials in the form of aerosols, powders, and gases.

Dose - The amount of energy deposited in body tissue due to radiation exposure. This is distinguished from absorbed dose which is the energy absorbed by matter from ionizing radiation per unit mass at the point of interest.

Dose Equivalent - The product of absorbed dose multiplied by a quality factor multiplied by a distribution factor. It is expressed numerically in rem.

Encapsulate - To enclose in, or as if in a capsule.

Fume Hood - An exhausted enclosure with a horizontal or vertical moveable sash at the front to permit the use of the hands to manipulate materials and equipment located within.

Glovebox - A windowed, low-leakage enclosure equipped with one or more pairs of flexible gloves to allow personnel on the outside to handle radioactive material within the enclosure.

High Radiation Area - For facility designs, high radiation areas are areas where radiation levels are anticipated in excess of 1 mSv/h.

Hot Cell - A shielded enclosure fitted with suitable manipulator systems to allow the performance of operations involving highly radioactive material at reduced rates of exposure.

Human Factors - The applied science of the design or adaptation of machines, structures, or procedures for efficient use by humans.

Isokinetic - A condition which prevails when the velocity of air entering a sampling probe or the collector when held in the airstream is identical to the velocity of the airstream being sampled at that point.

Radiation Area - A radiation area is any location accessable to individuals where the anticipated dose rate exceeds 0.005 mSv/h.

Sealed Radioactive Material - Radioactive material that is encased in a capsule, or having a bonded cover, designed to prevent leakage or escape of the radioactive material.

Single Failure - An occurrence that results in the loss of capability of a component to perform its intended safety function(s). Multiple failures, i.e., loss of capability of several components, resulting from a single occurrence are considered to be a single failure. Systems are considered to be designed against an assumed single failure if neither (1) a single failure of any active component (assuming passive components function properly) nor, (2) a single failure of any passive component (assuming active components function properly) results in loss of the system's capability to perform its safety function(s).

Sphincter Seal - A cylindrical port containing a series of internal, equally-spaced, resilient, washer-like seals through which cylindrical containers can be pushed into a glovebox without opening the contaminated space to the room atmosphere.

Waste - Solid, liquid, and/or gaseous radioactive materials that are generated by, or resulting from, nuclear operations or work performed with radioactive material that have no foreseeable use or need.

REFERENCES

ACGIH, Industrial Ventilation.

ANSI N2.3, Immediate Evacuation Signal for Use in Industrial Installations Where Radiation Exposure May Occur.

ANSI N13.1, Guide to Sampling Airborne Radioactive Materials in Nuclear Facilities.

ANSI N43.1, Radiological Safety in the Design and Operation of Partical Accelerators.

ANSI N43.2, Radiation Safety for X-Ray Diffraction and Fluorescence Analysis Equipment.

ANSI N320, Performance Specification for Reactor Emergency Radiological Monitoring Instrumentation.

ANSI N512, Protective Coatings (Paints) for the Nuclear Industry,

ANSI N543, General Safety Standard for Installations Using Non-Medical X-Ray and Sealed Gamma-Ray Sources, Energies up to 10 MeV.

ANSI Z53.1, Safety Color Code for Marking Industrial Hazards.

ANSI/ASME C852-81, Standard Design Criteria for Plutonium Gloveboxes.

ASHRAE Handbook, Fundimentals.

ASHRAE Handbook, HVAC Systems and Equipment.

ASHRAE, Heating, Ventilating and Air-Conditioning Design Guide for Department of Energy Nuclear Nacilities.

ASHRAE Standard 110, Method of Testing Performance of Laboratory Fume Hoods.

ASME N509, Nuclear Power Plant Air Cleaning Units and Components.

ASME N510, Testing of Nuclear Air Cleaning Systems.

ICRP 26, Recommendations of the International Commission on Radiation Protection.

ICRP 37, Cost-Benefit Analysis in the Optimazation of Radiation Protection, 1983.

IES-CC-RP-008-84, High Efficiency Gas-Phase Adsorber Cells.

MIL-HDBK-743, Anthropometery of U. S. Military Personnel.

MIL-STD-1472, Human Engineering Design Criteria for Military Systems, Equipment and Facilities.

NCRP 39, Basic Radiation Protection Criteria, National Council on Radiation Protection and Measurements.

NCRP 49, Structural Shielding Design and Evaluation for Medical Use of X-Rays and Gamma-Rays of Energy up to 10 MeV.

NRCP 51, Radiation Protection Design Guidelines for 0.1-100 MeV Particle Accelerator Facilities.

McCormick and Sanders, Heman Factors in Engineering and Design, McGraw-Hill Book Co. 1982

Perry and Chilton, Chemical Engineers Handbook, McGraw-Hill Book Co.

Woodson, Human Factors Design Handbook, McGraw-Hill Book Co. 1981.

APPENDIX A

HUMAN FACTORS CONSIDERATIONS

The importance of human factors is becoming more widely recognized in the design of equipment. There are several reasons for this. One is the need for total reliability. This includes the reliability with which the human operator manipulates and uses equipment not just hardware reliability alone. In order to maximize the safety and reliability of any given design, human factors must be considered in the design.

Human factors is a discipline of its own. Therefore, the main human factors considerations in design will be handled separately.

Information on human factors may be obtained from the following references: McCormick, "Human Factors in Engineering and Design,"; Military Standard, "Human Engineering Design Criteria for Military Systems, Equipment and Facilities,"; Systems Safety development Center, "Human Factors in Design,"; and Woodson, "Human Factors Design Handbook."

1.0 GENERAL REQUIREMENTS

1.1 OBJECTIVES

Designs shall foster personnel safety and health and minimize discomfort, distraction, and any other factors which degrade human performance or increase error.

1.2 HUMAN ENGINEERING DESIGN

The design shall include consideration of human engineering and biomedical factors that affect human performance. This includes, when applicable:

1. Adequate space for personnel, equipment, and free volume for the movements required to be performed, during operation and maintenance tasks, under both normal and emergency conditions.

2. Adequate physical and visual links between personnel and the equipment under both normal and emergency conditions.

3. Efficient arrangements of process and maintenance equipment.

4. Adequate illumination for the performance of operations and maintenance.

5. Provisions for minimizing psychophysiological stress and fatigue during operations and maintenance.

6. Design features to assure rapidity, safety, ease, and economy of operation and maintenance in normal, adverse, and emergency maintenance environments.

7. Satisfactory remote handling provisions and tools, if needed.

1.3 SIMPLICITY OF DESIGN

The equipment shall represent the simplest design consistent with functional requirements and expected service conditions.

1.4 SAFETY

Consideration shall be given to safety factors, including minimization of potential human error in the operation and maintenance of the system under all conditions.

2.0 ANTHROPOMETRY

2.1 GENERAL

The design of equipment and location of windows, equipment, etc. shall ensure accommodation, compatibility, operability, and maintainability by the user population as:

1. Generally, design limits shall be based upon values for critical body dimensions ranging from the 5th percentile female to the 95th percentile male, as appropriate. For any body dimension, the 5th percentile value indicates that five percent of the population will be equal to or smaller than that value and 95 percent will be larger; conversely, the 95th percentile values indicates that 95 percent of the population will be equal to or smaller than that value and five percent will be larger. Therefore, use of a design range from the 5th to 95th percentile values will theoretically provide coverage for 90 percent of the user population for that dimension.

2. Where two or more dimensions are used simultaneously as design parameters, appropriate multivariate data and techniques should be utilized.

2.2 ANTHROPOMETRIC DATA

The limited anthropometric data presented in this Appendix in Tables 1 through 5, and Figures 1 through 10, are intended to provide general design guidance. "Anthropometry of U.S. Military Personnel," MIL-HDBK, should be consulted for more extensive data. Use of these data must take the following into consideration:

1. The nature, frequency, and difficulty of the related tasks to be performed by the operator.

2. The position of the body during performance of these tasks.

3. Mobility or flexibility requirements imposed by these tasks.

The anthropometric data presented in Tables 1 through 5 are nude body measurements; data in centimeters are given in the upper half of each table, and data in inches are shown in the lower half of each table. (NOTE: The anthropometric data shown in these tables have been compiled and collated from several sources. The data on men consist of measurements on a series of ground troops broken down as follows: 6682 U.S. Army men and 2008 U.S. Marines, both measured in 1966, as

well as of 287 U.S. Army men measured in 1977. The data on women consist of measurements of 1300 U.S. Army WAC personnel and Army nurses measured in 1977; and 1905 U.S. Air Force WAF personnel and Air Force nurses measured in 1968.)

2.3 USE OF ANTHROPOMETRIC DATA

2.3.1 Data Limitations

Because the anthropometric data presented here represent nude body measurements, suitable allowances shall be made for light or heavy clothing, radiological protection clothing, shoes, etc. when utilizing these data for design.

2.3.2 Clearance Dimensions

Clearance dimensions, which must accommodate or allow passage of the body or parts of the body, shall be based upon the 95th percentile values for applicable body dimensions.

2.3.3 Limiting Dimensions

Limiting dimensions, which restrict or are limited by extensions of the body, shall be based upon the 5th percentile values for applicable body dimensions.

2.3.4 Adjustable Dimensions

Any equipment that must be adjusted for the comfort or performance of the individual user shall be adjustable over the range of the 5th to 95th percentile values for the applicable body member(s).

2.4 SPECIFIC GLOVEBOX CONSIDERATIONS

2.4.1 Windows

Windows shall be conveniently located for the worker size range specified in Section 2.1. Windows should be angled and positioned with eye and head rotation, line of sight, and maximum lateral viewing zone considered (refer to Figures 9, 10, and 11).

2.4.2 Ports

Glove ports shall be located (with respect to height, total number, and distance between) to accommodate the 5th and 95th percentile size range for applicable body dimensions (refer to Figures 11 and 12). The use of accessory equipment (e.g., platforms) should be considered in determining glove port location.

2.4.3 Accessibility

Depth of the glovebox and accessibility of all portions of the glovebox shall be based on the 5th percentile values for applicable body dimensions (refer to Figures 11 and 12). Use of accessories to obtain access to certain portions of the glovebox interior may be considered.

Table A-1. Standing Body Dimensions.

		PERCENTILE VALUES IN CENTIMETERS			
		5TH PERCENTILE		95TH PERCENTILE	
		MEN	WOMEN	MEN	WOMEN
	WEIGHT (kg)	55.5	46.4	91.6	74.5
STANDING BODY DIMENSIONS					
1.	Stature	162.8	152.4	185.6	174.1
2.	Eye Height	151.1	140.9	173.3	162.2
3.	Shoulder Height	133.6	123.0	154.2	143.7
4.	Chest Height	117.9	109.3	136.5	127.8
5.	Elbow Height	101.0	94.9	117.8	110.7
6.	Waist Height	96.6	93.1	115.2	110.3
7.	Crotch Height	76.3	68.1	91.8	83.9
8.	Gluteal Furrow Height	73.3	66.4	87.7	81.0
9.	Kneecap Height	47.5	43.8	58.6	52.5
10.	Calf Height	31.1	29.0	40.6	36.6
11.	Functional Reach	72.6	64.0	90.9	80.4
12.	Functional Reach, Extended	84.2	73.5	101.2	92.7
		PERCENTILE VALUES IN INCHES			
	WEIGHT (lb)	122.4	102.3	201.9	164.3
STANDING BODY DIMENSIONS					
1.	Stature	64.1	60.0	73.1	68.5
2.	Eye Height	59.5	55.5	68.2	63.9
3.	Shoulder Height	52.6	48.4	60.7	56.6
4.	Chest Height	46.4	43.0	53.7	50.3
5.	Elbow Height	39.8	37.4	46.4	43.6
6.	Waist Height	38.0	36.6	45.3	43.4
7.	Crotch Height	30.0	26.8	36.1	33.0
8.	Gluteal Furrow Height	28.8	26.2	34.5	31.9
9.	Kneecap Height	18.7	17.2	23.1	20.7
10.	Calf Height	12.2	11.4	16.0	14.4
11.	Functional Reach	28.6	25.2	35.8	31.7
12.	Functional Reach, Extended	33.2	28.9	39.8	36.5

Table A-2. Seated Body Dimensions.

		PERCENTILE VALUES IN CENTIMETERS			
		5TH PERCENTILE		95TH PERCENTILE	
		MEN	WOMEN	MEN	WOMEN
SEATED BODY DIMENSIONS					
13.	Vertical Arm Reach	128.6	117.4	147.8	139.4
14.	Sitting Height, Erect	83.5	79.0	96.9	90.9
15.	Sitting Height, Relaxed	81.5	77.5	94.8	89.7
16.	Eye Height, Sitting Erect	72.0	67.7	84.6	79.1
17.	Eye Height, Sitting Relaxed	70.0	66.2	82.5	77.9
18.	Mid-Shoulder	56.6	53.7	67.7	62.5
19.	Shoulder Height	54.2	49.9	65.4	60.3
20.	Shoulder-Elbow Length	33.3	30.8	40.2	36.6
21.	Elbow-Grip Length	31.7	29.6	38.3	35.4
22.	Elbow-Fingertip Length	43.8	40.0	52.0	47.5
23.	Elbow Rest Height	17.5	16.1	28.0	26.9
24.	Thigh Clearance Height		10.4		17.5
25.	Knee Height, Sitting	49.7	46.9	60.2	55.5
26.	Popliteal Height	39.7	38.0	50.0	45.7
27.	Buttock-Knee Length	54.9	53.1	65.8	63.2
28.	Buttock-Popliteal Length	45.8	43.4	54.5	52.6
29.	Functional Leg Length	110.6	99.6	127.7	118.6

		PERCENTILE VALUES IN INCHES			
SEATED BODY DIMENSIONS					
13.	Vertical Arm Reach	50.6	46.2	58.2	54.9
14.	Sitting Height, Erect	32.9	31.1	38.2	35.8
15.	Sitting Height, Relaxed	32.1	30.5	37.3	35.3
16.	Eye Height, Sitting Erect	28.3	26.6	33.3	31.2
17.	Eye Height	27.6	26.1	32.5	30.7
18.	Mid-Shoulder Height	22.3	21.2	26.7	24.6
19.	Shoulder Height	21.3	19.6	25.7	23.7
20.	Shoulder-Elbow Length	13.1	12.1	15.8	14.4
21.	Elbow-Grip Length	12.5	11.6	15.1	14.0
22.	Elbow-Fingertip Length	17.3	15.7	20.5	18.7
23.	Elbow Rest Height	6.9	6.4	11.0	10.6
24.	Thigh Clearance Height		4.1		6.9
25.	Knee Height	19.6	18.5	23.7	21.8
26.	Popliteal Height	15.6	15.0	19.7	18.0
27.	Buttock-Knee Length	21.6	20.9	25.9	24.9
28.	Buttock-Popliteal Length	17.9	17.1	21.5	20.7
29.	Functional Leg Length	43.5	39.2	50.3	46.7

Table A-3. Depth and Breadth Dimensions.

		PERCENTILE VALUES IN CENTIMETERS			
		5TH PERCENTILE		95TH PERCENTILE	
		MEN	WOMEN	MEN	WOMEN
DEPTH AND BREADTH DIMENSIONS					
30.	Chest Depth	18.9	19.6	26.7	27.2
31.	Buttock Depth		18.4		24.3
32.	Chest Breadth	27.3	25.1	34.4	31.4
33.	Hip Breadth, Standing	30.2	31.5	36.7	39.5
34.	Shoulder	41.5	38.2	49.8	45.8
35.	Forearm-Forearm Breadth	39.8	33.0	53.6	44.9
36.	Hip Breadth, Sitting	30.7	33.0	38.4	43.9

		PERCENTILE VALUES IN INCHES			
DEPTH AND BREADTH DIMENSIONS					
30.	Chest Depth	7.5	7.7	10.5	10.7
31.	Buttock Depth, Standing		7.2		9.6
32.	Chest Breadth	10.8	9.9	13.5	12.4
33.	Hip Breadth, Standing	11.9	12.4	14.5	15.6
34.	Shoulder Breadth	16.3	15.0	19.6	18.0
35.	Forearm-Forearm Breadth	15.7	13.0	21.1	17.7
36.	Hip Breadth, Sitting	12.1	13.0	15.1	17.3

Table A-4. Hand and Foot Dimensions.

		PERCENTILE VALUES IN CENTIMETERS			
		5TH PERCENTILE		95TH PERCENTILE	
		MEN	WOMEN	MEN	WOMEN
HAND DIMENSIONS					
37.	Hand Length	17.4	16.1	20.7	20.0
38.	Palm Length(Standing)	9.6	9.0	11.7	10.8
39.	Hand Breadth	8.1	6.9	9.7	8.5
40.	Hand Circumference	19.5	16.8	23.6	19.9
FOOT DIMENSIONS					
41.	Foot Length	24.5	22.2	29.0	26.5
42.	Instep Length	17.7	16.3	21.7	19.6
43.	Foot Breadth	9.0	8.0	10.9	9.8
44.	Foot Circumference	22.5	20.8	27.4	24.5
45.	Heel-Ankle Circumference	31.3	28.5	37.0	33.3
		PERCENTILE VALUES IN INCHES			
HAND DIMENSIONS					
37.	Hand Length	6.9	6.3	8.1	7.9
38.	Palm Length	3.8	3.6	4.6	4.2
39.	Hand Breadth	3.2	2.7	3.8	3.3
40.	Hand Circumference	7.7	6.6	9.3	7.8
FOOT DIMENSIONS					
41.	Foot Length	9.7	8.7	11.4	10.4
42.	Instep Length	7.0	6.4	8.5	7.7
43.	Foot Breadth	3.5	3.2	4.3	3.8
44.	Foot Circumference	8.9	8.2	10.8	9.7
45.	Heel-Ankle Circumference	12.3	11.2	14.6	13.1

Table A-5. Anthropometric Data for Common Working Positions.

		PERCENTILE VALUES IN CENTIMETERS			
		5TH PERCENTILE		95TH PERCENTILE	
		MEN	WOMEN	MEN	WOMEN
1.	Weight-Clothed (Kilograms)	58.6	48.8	90.2	74.6
2.	Stature-Clothed	168.5	156.8	189.0	178.7
3.	Functional Reach	72.6	64.0	86.4	79.0
4.	Functional Reach Extended	84.2	73.5	101.2	92.7
5.	Overhead Reach Height	200.4	185.3	230.5	215.1
6.	Overhead Reach Breadth	35.2	31.5	41.9	37.9
7.	Bent Torso Height	125.6	112.7	149.8	138.6
8.	Bent Torso Breadth	40.9	36.8	48.3	43.5
9.	Overhead Reach, Sitting	127.9	117.4	146.9	139.4
10.	Functional Leg Length	110.6	99.6	127.7	118.6
11.	Kneeling Height	121.9	114.5	136.9	130.3
12.	Kneeling Leg Length	63.9	59.2	75.5	70.5
13.	Bent Knee Height, Supine	44.7	41.3	53.5	49.6
14.	Horizontal Length, Knees Bent	150.8	140.3	173.0	163.8
		PERCENTILE VALUES IN INCHES			
1.	Weight-Clothed (Pounds)	129.1	107.6	198.8	164.5
2.	Stature-Clothed	66.4	61.8	74.4	70.3
3.	Functional Reach	28.6	25.2	34.0	31.1
4.	Functional Reach, Extended	33.2	28.9	39.8	36.5
5.	Overhead Reach Height	78.9	73.0	90.8	84.7
6.	Overhead Reach Breadth	13.9	12.4	16.5	14.9
7.	Bent Torso Height	49.4	44.4	59.0	54.6
8.	Bent Torso Breadth	16.1	14.5	19.0	17.1
9.	Overhead Reach, Sitting	50.3	46.2	57.9	54.9
10.	Functional Leg Length	43.5	39.2	50.3	46.7
11.	Kneeling Height	48.0	45.1	53.9	51.3
12.	Kneeling Leg Length	25.2	23.3	29.7	27.8
13.	Bent Knee Height Supine	17.6	16.3	21.1	19.5
14.	Horizontal Length, Knees Bent	59.4	55.2	68.1	64.5