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StandardGuide for
General Design Considerations for Hot Cell Equipment[1]

This standard is issued under the fixed designation C1533; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 *Intent:*

1.1.1 The intent of this guide is to provide general design and operating considerations for the safe and dependable operation of remotely operated hot cell equipment. Hot cell equipment is hardware used to handle, process, or analyze nuclear or radioactive material in a shielded room. The equipment is placed behind radiation shield walls and cannot be directly accessed by the operators or by maintenance personnel because of the radiation exposure hazards. Therefore, the equipment is operated remotely, either with or without the aid of viewing.

1.1.2 This guide may apply to equipment in other radioactive remotely operated facilities such as suited entry repair areas, canyons or caves, but does not apply to equipment used in commercial power reactors.

1.1.3 This guide does not apply to equipment used in gloveboxes.

1.2 *Applicability:*

1.2.1 This guide is intended for persons who are tasked with the planning, design, procurement, fabrication, installation, or testing of equipment used in remote hot cell environments.

1.2.2 The equipment will generally be used over a long-term life cycle (for example, in excess of two years), but equipment intended for use over a shorter life cycle is not excluded.

1.2.3 The system of units employed in this standard is the metric unit, also known as SI Units, which are commonly used for International Systems, and defined by IEEE/ASTM SI 10: American National Standard for Use of the International System of Units (SI): The Modern Metric System.

1.3 *Caveats:*

1.3.1 This guide does not address considerations relating to the design, construction, operation, or safety of hot cells, caves, canyons, or other similar remote facilities. This guide deals only with equipment intended for use in hot cells.

1.3.2 Specific design and operating considerations are found in other ASTM documents.

1.4 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory requirements prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

A193/A193M Specification for Alloy-Steel and Stainless Steel Bolting for High Temperature or High Pressure Service and Other Special Purpose Applications
A240/A240M Specification for Chromium and Chromium-Nickel Stainless Steel Plate, Sheet, and Strip for Pressure Vessels and for General Applications
A276 Specification for Stainless Steel Bars and Shapes
A320/A320M Specification for Alloy-Steel and Stainless Steel Bolting for Low-Temperature Service
A354 Specification for Quenched and Tempered Alloy Steel Bolts, Studs, and Other Externally Threaded Fasteners
A479/A479M Specification for Stainless Steel Bars and Shapes for Use in Boilers and Other Pressure Vessels
A489 Specification for Carbon Steel Lifting Eyes
A490 Specification for Structural Bolts, Alloy Steel, Heat Treated, 150 ksi Minimum Tensile Strength
C859 Terminology Relating to Nuclear Materials
C1217 Guide for Design of Equipment for Processing Nuclear and Radioactive Materials
C1554 Guide for Materials Handling Equipment for Hot Cells
C1572 Guide for Dry Lead Glass and Oil-Filled Lead Glass Radiation Shielding Window Components for Remotely Operated Facilities
C1615 Guide for Mechanical Drive Systems for Remote Operation in Hot Cell Facilities
C1661 Guide for Viewing Systems for Remotely Operated Facilities
D676 Method of Test for Indentation of Rubber by Means of a Durometer; Replaced by D 2240 (Withdrawn 1964)[3]

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[1] This guide is under the jurisdiction of ASTM Committee C26 on Nuclear Fuel Cycle and is the direct responsibility of Subcommittee C26.14 on Remote Systems.

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[3] The last approved version of this historical standard is referenced on www.astm.org.

D5144 Guide for Use of Protective Coating Standards in Nuclear Power Plants

E170 Terminology Relating to Radiation Measurements and Dosimetry

F593 Specification for Stainless Steel Bolts, Hex Cap Screws, and Studs

IEEE/ASTM SI 10 American National Standard for Use of the International System of Units (SI): The Modern Metric System

2.2 *Other Standards:*

10CFR830.120 Nuclear Safety Management Quality Assurance Requirements[4]

ANSI/ANS-8.1 Nuclear Criticality Safety in Operations with Fissionable Materials Outside Reactors[5]

ANSI/ASME NQA-1 Quality Assurance Requirements for Nuclear Facility Applications[6]

ANSI/ISO/ASQ 9001 Quality Management Systems[5]

ASME Y14.5 Dimensioning and Tolerancing[6]

ICRU Report 10b Physical Aspects of Irradiation[7]

NCRP Report No. 82 SI Units in radiation Protection and Measurements[8]

3. Terminology

3.1 The terminology employed in this guide conforms to industry practice insofar as practicable.

3.2 For definitions of terms not described in this guide, refer to Terminology C859.

3.3 *Definitions of Terms Specific to This Standard:*

3.3.1 *canyon*—a long narrow, remotely operated and maintained radiological area within a facility where nuclear material is processed or stored.

3.3.2 *cave*—typically a small-scale hot cell facility, but is sometimes used synonymously with hot cell.

3.3.3 *dose equivalent*—the measure of radiation dose from all types of radiation expressed on a common scale. The specialized unit for dose equivalent is the rem. The SI unit for dose equivalent is the sievert (Sv), which is equal to 100 rem. Human exposure is often expressed in terms of microsieverts (µSV), 1×10^{-6} sieverts, or in terms of millirem (mrem),1×10^{-3}.

3.3.4 *electro-mechanical manipulator (E/M)*—usually mounted on a crane bridge, wall, pedestal, or ceiling and is used to handle heavy equipment in a hot cell. Each joint of the E/M is operated by an electric motor or electric actuator. The E/M is operated remotely using controls from the uncontaminated side of the hot cell. Most E/Ms have lifting capacities of 100 lbs or more.

3.3.5 *gamma radiation*—high energy, short wavelength electromagnetic radiation which normally accompanies the other forms of particle emissions during radioactive decay. Gamma radiation has no electrical charge.

3.3.6 *high density concrete*—a concrete having a mass of greater than 2400 kg per cubic meter (150 lb per cubic foot).

3.3.7 *hot cell*—an isolated shielded room that provides a controlled environment for containing highly radioactive and contaminated material and equipment. The radiation levels within a hot cell are typically 1 Gy/hr (100 rads per hour) or higher in air.

3.3.8 *master-slave manipulator (MSM)*—a device used to handle items, tools, or radioactive material in a hot cell. The in-cell or slave portion of the manipulator replicates the actions of an operator outside of the hot cell by means of a through-wall mechanical connection between the two, usually with metal tapes or cables. MSMs have lifting capacities of 9 to 23 kg (20 to 50 lb).

3.3.9 *mock-up*—a facility used to represent the physical environment of a radiological facility in a non-radiological setting. Mock-ups are full scale facilities used to assure proper clearances, accessibility, visibility, or operability of items to be subsequently installed in a radiological environment.

3.3.10 *radiation absorbed dose (rad)*—radiation absorbed dose is the quotient of the mean energy imparted by ionizing radiation to matter of mass. The SI unit for absorbed dose is the gray (NCRP Report No. 82).

3.3.11 *radiation streaming*—unshielded beams of radiation.

3.3.12 *roentgen equivalent man (rem)*—a measure of the damaging effects of ionizing radiation to man. See *dose equivalent* (NCRP Report No. 82, ICRU Report 10b).

4. Significance and Use

4.1 The purpose of this guide is to provide general guidelines for the design and operation of hot cell equipment to ensure longevity and reliability throughout the period of service.

4.2 It is intended that this guide record the general conditions and practices that experience has shown is necessary to minimize equipment failures and maximize the effectiveness and utility of hot cell equipment. It is also intended to alert designers to those features that are highly desirable for the selection of equipment that has proven reliable in high radiation environments.

4.3 This guide is intended as a supplement to other standards, and to federal and state regulations, codes, and criteria applicable to the design of equipment intended for hot cell use.

4.4 This guide is intended to be generic and to apply to a wide range of types and configurations of hot cell equipment.

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[4] Available from U.S. Government Printing Office Superintendent of Documents, 732 N. Capitol St., NW, Mail Stop: SDE, Washington, DC 20401, http://www.access.gpo.gov.

[5] Available from American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036, http://www.ansi.org.

[6] Available from American Society of Mechanical Engineers (ASME), ASME International Headquarters, Three Park Ave., New York, NY 10016-5990, http://www.asme.org.

[7] Available from International Commission on Radiation Units and Measurements, Inc., 7910 Woodmont Ave., Suite 400, Bethesda, MD 20814-3095, http://www.icru.org.

[8] Available from National Council of Radiation Protection and Measurements, 7910 Woodmont Ave., Suite 400, Bethesda, MD 20814-3095, http://www.ncrponline.org.

5. Quality Assurance Requirements

5.1 The manufacturer and Owner-Operator of hot cell equipment should have a quality assurance program. QA programs may be required to comply with 10CFR830.120, ANSI/ASME NQA-1, or ANSI/ISO/ASQ 9001.

5.2 The Owner-Operator should require appropriate quality assurance of purchased hot cell equipment to assure proper remote installation, operation and reliability of the components when they are installed in the hot cell.

5.3 Hot cell equipment should be designed according to quality assurance requirements and undergo quality control inspections as outlined by the authority having jurisdiction.

6. Nuclear Safety

6.1 The handling and processing of special nuclear materials requires the avoidance of criticality incidents. Equipment intended for use in handling materials having a special nuclear material content should undergo a criticality assessment analysis in accordance with the requirements of ANSI/ANS-8.1 and other such standards and regulations as may be applicable.

7. Design Considerations

7.1 Hot cell equipment should be designed and fabricated to remain dimensionally stable throughout its life cycle.

7.2 Fabrication materials should be resistant to radiation damage, or materials subject to such damage should be shielded or placed and attached so as to be readily replaceable.

7.3 Special consideration should be given to designing hot cell equipment that may be exposed to or may create high temperatures, high rate of temperature changes, caustic conditions, or pressure changes. Abrupt changes in the hot cell temperature or pressure may cause the hot cell windows to crack, lose clarity, and potentially lose containment and cause liquid spillage. Refer to Guide C1572 for information regarding hot cell windows. The effect of handling and operating high temperature hot cell equipment utilizing master-slave manipulators or other in-cell handling equipment should be considered to preclude damage to those items.

7.4 Preventive maintenance based on previous experience in similar environments and similar duty should be performed as required to prevent unscheduled repair of failed components.

7.5 Hot cell equipment may be required to be leak-tight when handling liquids. Leak tightness prevents radioactive liquid from entering the interior of hot cell equipment where it can cause corrosion, shorting of electrical components, higher chronic radiation to components and it complicates decontamination.

7.6 Hot cell equipment should generally be designed to function indefinitely, or within a pre-planned specified life cycle within the highly radioactive environment. However, in many cases this may not be possible since radiation degrades some materials over time. Alpha, beta, gamma, and neutron radiation can severely damage most organic materials, for example, oils, plastics, and elastomers. Materials that come into direct contact with alpha- and beta-emitting materials can experience severe radiation damage due to the large amount of energy transferred when stopping the alpha and beta particles. Commercially available equipment containing organic materials may require disassembly and the internal components replaced with more radiation resistant materials. If suitable alternate materials cannot be used, special shielding may have to be integrated into the design to protect the degradable components. In the case of some electronic equipment, it may be possible to separate and move the more radiation sensitive components outside of the hot cell and operate the equipment in the hot cell remotely. Where possible and appropriate, equipment should be designed to withstand an accumulative radiation dose of approximately 1×10^8 rads (H_2O)[^{60}Co].

7.7 Since hot cells have a limited amount of space, the equipment designs should be standardized where possible to reduce the number of one-of-a-kind parts. Standardization of hot cell equipment will reduce design time, fabrication costs, operator training time, maintenance costs, and the number of special tools required to perform a certain operation. Standardization in design, drawing control and excellent quality control assure that components are interchangeable. Specially designed equipment should be standardized for use with equipment in similar applications or systems to reduce spare parts inventories and to maintain familiarity for the operators. Commercially available components should be used, and modified if necessary, wherever possible in preference to specially designed equipment.

7.8 All hot cell equipment should be designed in modules for ease of replacement, maintainability, interchangeability, standardization, and ease of disposal. The modules should be designed to be remotely removable and installed using the in-cell handling equipment, that is, master-slave manipulators, cranes, etc. Consideration should also be given to the transfer path to get equipment into the hot cell and size equipment modules accordingly. Components with a higher probability of failure should be made modular for ease of replacement. Remotely operated electrical connectors must be compatible with the hot cell materials handling equipment. Drawings of hot cell equipment should reflect the as-built configuration for all replaceable components to provide reliable documentation control, and conform to ASME Y14.5 Dimensioning and Tolerancing. Interfacing components should be toleranced to fit the in-field conditions. Replaceable components should be labeled with a standard identification and the component weight. Examples of modular designs might include subassemblies of removable motors, resolvers, valves, limit switches, and electrical cables.

7.9 The hot cell atmosphere can have an adverse affect on hot cell equipment. Hot cells can have air or inert gas atmospheres and are usually kept at a negative differential pressure of 2.5 cm to 5 cm (1.0 to 2.0 in.) of water gauge with respect to the surrounding operating areas. Hot cells with inert atmospheres or very low moisture content can make it difficult to operate some types of equipment. Some brush type motors, for example, will stall or simply fail to operate. One solution has been to replace the motor brushes with high altitude type brushes made of silver-graphite or use brushless motors. A good understanding of the effects of the hot cell atmosphere on equipment is essential when purchasing or designing new hot cell equipment.

7.10 It is generally advisable to perform qualification testing on new hot cell equipment in a mockup facility prior to putting the equipment into service. The mockup generally uses the same equipment interfaces such as cranes, electro-mechanical manipulators, electrical/instrumentation connections, and master-slave manipulators as the hot cell. The mockup is generally located in a non-radioactive and non-contaminated area. Any new equipment to be used in a hot cell should be assembled, disassembled, and operated in the mockup to verify that it can be installed, removed, maintained, and operated successfully in the hot cell environment. The mockup area is also useful for training purposes and troubleshooting. Oftentimes the mockup testing will identify deficiencies in the equipment design or operation that without mockup testing would render the equipment useless in the hot cell. Care should be taken during the mockup testing and hardware installation to ensure that the operability and integrity of the equipment is not compromised.

7.11 Design considerations should include the limited capabilities of the overhead handling systems, the inability to have direct access to the equipment, and the limited viewing capabilities. Limitations include the top-only access for component replacement and the fact that operators will only be able to directly view one or two faces of the system. Equipment designs should provide for unobstructed viewing (directly or indirectly using cameras) of remotely separable interfaces so that any tools or equipment needed to perform the in-cell maintenance functions can be engaged, disengaged, or positioned in full view (see Guide C1661). The equipment modules should be designed so that they can be reached, disconnected, and maneuvered using the in-cell materials handling equipment (see Guide C1554).

7.12 Hot cell equipment should be designed with assembly features to assure accurate positioning, aligning, mating, and fastening of components. Examples include alignment pins, captured bolts, countersink or tapered guides, and thread lead-ins. Close attention to fabrication tolerances is essential to ensure that replaceable parts are interchangeable. Refer to other standards referenced in Fig. 1 or in Appendix X3. These devices should also be completely tested in the mock-up facilities.

7.13 The method of hot cell equipment repair should be considered during the design phase. Typically, it is difficult to perform repairs of failed hot cell components. The preferred practice is to disassemble and replace failed components rather than attempting to repair the failed part. Equipment that cannot be repaired or replaced using the in-cell handling systems is generally transferred to a suited entry repair area where personnel in anti-contamination clothing perform hands-on repairs. Equipment that will be repaired in a suited entry repair area should be capable of being decontaminated to levels suitable for contact maintenance.

7.14 Hot cell designed equipment should include design features to minimize the amount of decontamination required for repair or disposal. Since the method of decontamination may involve rigorous chemical cleaning and decontamination procedures, the choice of component materials should be compatible with the decontamination techniques and solutions. For example, some decontamination solutions may not be compatible with aluminum. All surfaces should have a smooth finish, such as a 3.2 µm (125 micro-inch) or better, to make the items easier to decontaminate for disposal or repair. Contamination "traps" in equipment should be avoided or eliminated where possible. Hollow pedestals welded on equipment for the mounting of motors, gearboxes, bearings, and like components should not have through holes or threaded openings. The use of

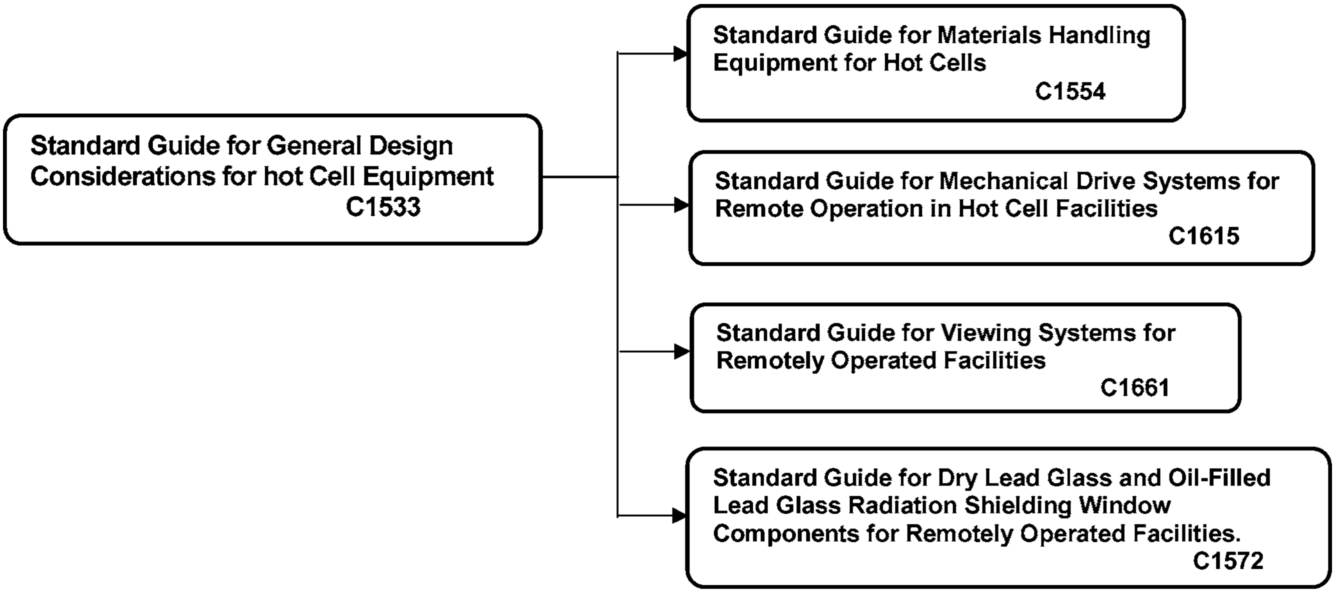

FIG. 1 Hierarchy of Hot Cell Equipment Design Guides

non-hazardous solutions during decontamination procedures is essential to prevent the generation of mixed wastes for disposal.

7.15 The ultimate disposal of hot cell equipment should always be considered early in the design process. Equipment that has been in a hot cell for an extended period of time may be difficult to decontaminate to acceptable levels for disposal because of the amount of fixed contamination. Also, some materials may become activated when exposed to radiation over a period of time, which may cause the material to be classified as a mixed hazardous waste. The use of these materials should be avoided where possible because of the complications of disposal. Components that are fastened together are sometimes preferable to welded components because they are easier to disassemble into sections more suitable for disposal and can sometimes be done remotely using manipulators. Where welding components together is required, skip welding should be avoided to prevent potential contamination traps. Welded components may require specialized cutting equipment in a contaminated room by personnel in anti-contamination clothing to reduce the size of the hardware in order to fit it into waste disposal containers. These operations increase the radiation exposure to personnel. Designers should become familiar with the specific contaminated equipment disposal methods at their facilities and incorporate equipment design features to reduce the disposal time, cost, and radiation exposure to personnel.

7.16 The interfacing systems should be factored into the hot cell equipment design. Master-slave manipulators positioned above the windows and overhead crane or electro-mechanical manipulator systems are used to operate and handle the hot cell equipment. The designer should consider the location of the equipment in the hot cell and its proximity to the master-slave manipulators, electro-mechanical manipulators, cranes, and service penetrations. Small removable equipment modules should be designed based on the type of master-slave manipulator grip, lifting capacity, and reach. The lifting capacity of master-slave manipulators is typically 4.5 to 23 kg (10 to 50 lb), but often much less depending on the arm reach during the lift. The designer should consider the capabilities of the manipulator intended for an application before designing the related hot cell equipment. Larger and heavier equipment should have design features to interface with the lifting cranes or electro-mechanical manipulators.

7.17 The agency of jurisdiction should dictate the requirements for the seismic design of hot cell equipment, if required. Generally, the equipment should be sufficiently robust to withstand failure during a seismic event, and should incorporate design features to prevent failure to other equipment or to the cell boundary.

7.18 Hot cells may include fixed floor reference or indexing points for accurate and consistent placement of components and anchoring of modules. The reference hardware should be robust enough to remain viable during the life of the cell and be replicated in the mock-up facility.

7.19 Some hot cells may be equipped with fire suppression systems. Consideration should be given to designing the hot cell equipment to mitigate the possible adverse affects of the fire suppression system activating.

8. Materials of Construction

8.1 *General Considerations for Metals and Alloys:*

8.1.1 It is highly desirable that corrosion resistant alloys or metals be used for hot cell equipment wherever possible. Carbon steels, copper, aluminum, and other readily oxidized materials capture and retain radioactive contaminants in the rust and corrosion layers. Rust and oxidation complicate the decontamination effort, making it a difficult and time-consuming task to reduce the radiation and contamination on the equipment to very low levels and the radiation exposures of maintenance personnel may be needlessly increased. Consideration should be given to ensuring that the unprotected materials of construction and equipment are resistant to corrosion and fixed contamination for the chemical decontamination processes and hot cell atmosphere.

8.1.2 Aluminum is sometimes used for in-cell equipment because it is light and can be easily handled using the master-slave manipulators. However, aluminum is soft and can be easily scratched, creating crevices for fixed contamination. Where aluminum is necessary, consideration should be given to hard anodizing the aluminum or plating the aluminum with nickel/zinc or electroless nickel to prevent oxidation and reduce the potential for fixed contamination.

8.1.3 The choice of materials for bolting hot cell equipment together is very important. The mating parts should be made of dissimilar metals to prevent galling. Examples of dissimilar metals that minimize galling when used on mating parts are Specifications A240/A240M, A276, and A479/A479M Type 304 and Type 316 Stainless Steels; Specification A193/A193M nitrogen strengthened austenitic steels such as UNS-S21800, and Specifications A320/A320M or A354 steels. Also, consideration should be given to the size of the bolts. Typically, bolts smaller than 10 mm (0.375 in.) in diameter should not be used since they are difficult to see and handle and are easily broken. When using master-slave manipulators, it is often difficult to determine how much force the operator is applying to a fastener. Loose nuts are typically not used to fasten hot cell equipment because of the difficulty in handling. Socket head cap screws are a good choice for hot cell equipment because they are easier to install and remove with master-slave manipulators than standard hex head bolts. Cone-headed hex bolts are also frequently used in hot cells, especially for use with electro-mechanical manipulators. If possible, cone-headed hex head bolts should all be the same size. Consideration should be given to ensure that suspect or counterfeit parts are not included in the hot cell equipment.

8.1.4 It is generally advisable to require material certification reports for all materials of construction for new hot cell equipment. Chemical or physical test reports may also be required for hot cell equipment whose failure due to materials of construction may pose a safety hazard or may severely impact program goals and operations.

8.1.5 Stainless alloys, as well as some other metals are highly susceptible to stress corrosion cracking. Hot cell equipment used in aqueous processes susceptible to stress corrosion cracking should limit the chloride content in the materials of construction. It is also imperative that all materials used in, and coming in contact with the equipment during the fabrication, testing, shipping, handling, and installation sequences be tested for their chloride content before being used, and the actual chloride content be documented. The constraint against the presence of chlorides also applies to other halides such as fluorides and bromides.

8.2 *General Considerations for Paint and Coatings:*

8.2.1 Generally, it is not advisable to paint hot cell components. Over time, the paint may chip or wear off due to rubbing contact with other components. Areas with chipped paint become sources of fixed contamination because radioactive particles get into the gap between the paint and the metal. Experience has shown that painted components are difficult and time consuming to decontaminate. Where it is impractical or unnecessary to use stainless steels or the cost of the materials or fabrication is prohibitive, painting carbon steel with epoxy coatings may be an acceptable alternative. Paint and strippable coatings should comply with Guide D5144.

8.2.2 Commercially produced equipment such as motors, gear reducers, and like components having baked enamel finishes are acceptable when used in applications and placed in locations where the components are readily removable and replaceable.

8.3 *General Considerations for Nonmetallic Materials:*

8.3.1 References providing information on the resistance to radiation damage and the effects of such damage to a variety of commonly used materials can be found in Appendix X1. This information covers material for gasketing, sealing, lubrication, thermal insulation cements, wire insulation, coatings, adsorption (ion exchange) resins, and other materials or components commonly used in hot cells. Materials that come into direct contact with alpha- and beta-emitting materials can experience severe radiation damage due to the large amount of energy transferred when stopping the alpha and beta particles. Using this information as a guide, the performance of these same materials under given radiation exposure conditions is generally predictable within an acceptable margin for error.

8.3.2 Materials subject to radiation damage should be configured and placed so as to be readily and separately removable. When this is not practicable, these materials should be placed on removable components or sub-assemblies rather than on the larger or main equipment item to facilitate removal and replacement.

8.3.3 When the use of materials and components susceptible to radiation damage and failure is unavoidable, the provision of a shield or placement of such materials or devices in a shielded location or areas of lower radiation will extend the service life of the susceptible materials or components.

8.3.4 The use of solid state circuitry in a radiation environment should be avoided if possible. Radiation hardened components or shielding should be considered if solid state circuitry is to be used in a hot cell. Solid state devices in a hot cell can fail in a variety of unpredictable ways. For example, circuitry that performs a switching or counting function can be switched or activated by exposure to radiation. Whenever such components or circuitry are used, their failure should place the equipment in a configuration suitable for device replacement and also place the equipment in an appropriate fail-safe mode so that hazards are not created in the equipment or systems.

9. Keywords

9.1 design; equipment; hot cell; manipulator; remote

APPENDIXES

(Nonmandatory Information)

X1. MISCELLANEOUS TECHNICAL REFERENCES

X1.1 Documents having applicability to the design, fabrication, inspection, testing, and installation of equipment used in the subject service environments include the following:

X1.1.1 "Handbook of Radiation Effects—Edition 2," Andrew Holmes-Siedle and Len Adams, Oxford University Press (2002), ISBN-10: 019850733X, ISBN-13: 978-0198507338.

X1.1.2 Various titles covering radiation damage, various authors, *Nucleonics*, Vol 13, No. 10, Oct. 1955; Vol 14, No. 9, September 1956; Vol 18, No. 9, Sept. 1960.

X1.1.3 REIC Report No. 21 "The Effect of Nuclear Radiation on Elastomeric and Plastic Components and Materials," Radiation Effects Information Center, Battelle Memorial Institute, 1964 (see also Addendum to Report 21).

X1.1.4 REIC Report No. 36 "The Effect of Nuclear Radiation on Electronics Components Including Semiconductors," Radiation Effects Information Center, Battelle Memorial Institute, 1964.

X1.1.5 "Radiation Damage of Materials Engineering Handbook: Part I: A Guide to the Use of Plastic," M. H. Vande Voorde and G. Pluym, European Organization for Nuclear Research, Geneva, Switzerland (1966).

X1.1.6 "Radiation Damage of Materials Engineering Handbook: Part II: A Guide to the Use of Elastomers," M. H. Vande Voorde, European Organization for Nuclear Research, Geneva, Switzerland (1966).