Designation: C 1554 – 03

Standard Guide for Materials Handling Equipment for Hot Cells[1]

This standard is issued under the fixed designation C 1554; 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 This guide covers materials handling equipment used in hot cells (shielded cells) for the processing and handling of nuclear and radioactive materials. The intent of this guide is to aid in the selection and design of materials handling equipment for hot cells in order to minimize equipment failures and maximize the equipment utility.

1.1.2 It is intended that this guide record the principles and caveats that experience has shown to be essential to the design, fabrication, installation, maintenance, repair, replacement, and decontamination and decommissioning of materials handling equipment capable of meeting the stringent demands of operating, dependably and safely, in a hot cell environment where operator visibility is limited due to the radiation exposure hazards.

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

1.1.4 This guide covers mechanical master-slave manipulators and electro-mechanical manipulators, but does not cover electro-hydraulic manipulators.

1.2 *Applicability*:

1.2.1 This guide is intended to be applicable to equipment used under one or more of the following conditions:

1.2.1.1 The materials handled or processed constitute a significant radiation hazard to man or to the environment.

1.2.1.2 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.

1.2.1.3 The equipment can neither be accessed directly for purposes of operation or maintenance, nor can the equipment be viewed directly, e.g., without shielded viewing windows, periscopes, or a video monitoring system.

1.3 *User Caveats*:

1.3.1 This standard is not a substitute for applied engineering skills, proven practices and experience. Its purpose is to provide guidance.

1.3.1.1 The guidance set forth in this standard relating to design of equipment is intended only to alert designers and engineers to those features, conditions, and procedures that have been found necessary or highly desirable to the design, selection, operation and maintenance of reliable materials handling equipment for the subject service conditions.

1.3.1.2 The guidance set forth results from discoveries of conditions, practices, features, or lack of features that were found to be sources of operational or maintenance problems, or causes of failure.

1.3.2 This standard does not supersede federal and/or state regulations, or codes applicable to equipment under any conditions.

1.3.3 This standard does not cover design features of the hot cell, e.g., windows, drains, and shield plugs. This standard does not cover pneumatic or hydraulic systems. Refer to Guides C 1533, C 1217, and ANS Design Guides for Radioactive Material Handling Facilities & Equipment for information and references to design features of the hot cell and other hot cell equipment.

1.3.4 *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 limitations prior to use.*

2. Referenced Documents

2.1 *Industry and National Consensus Standards*—Nationally recognized industry and consensus standards applicable in whole or in part to the design, fabrication, and installation of equipment are referenced throughout this guide and include, but are not limited to, the following:

2.2 *ASTM Standards*:[2]

C 859 Terminology Relating to Nuclear Materials[3]

C 1217 Guide for Design of Equipment for Processing Nuclear and Radioactive Materials[3]

C 1533 Guide for General Design Considerations for Hot Cell Equipment[3]

2.3 *Other Standards:*

[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] *Annual Book of ASTM Standards*, Vol 12.01.

AAI A14.3 Ladders, Fixed Safety Requirements, OSHA[4]
ANS 8.1 Nuclear Criticality Safety in Operations with Fissile Materials Outside Reactors[5]
ANS Design Guides for Radioactive Material Handling Facilities & Equipment, ISBN: 0-89448-554-7[5]
ASSE SA/SAFE Ladders, Fixed Safety Requirements, OSHA[5]
ANSI B30.2 Overhead and Gantry Cranes[6]
ASME NQA 1 Quality Assurance Requirements for Nuclear Facility Applications[7]
ASME NOG-1 Rules for Construction of Overhead Gantry Cranes (Top-Running Bridge, Multiple Girder)[7]
ISO/TC 85/SC 2 N 637 E Remote Handling Devices for Radioactive Materials—Part 1 : General Requirements[8]
ISO 9001 Quality Management Systems Requirements[8]
NEMA 250 Enclosures for Electrical Equipment 1000 Volts Maximum (Type 4)[9]
NFPA 70 National Electric Code[10]

2.4 *Federal Regulations:*

10CFR50 Appendix B, Quality Assurance[11]
10CFR830.120 Nuclear Safety Management Quality Assurance Requirements[11]
29CFR1910 Occupational Safety and Health Standards[11]
40CFR 260-279 Solid Waste Regulations[11]

3. Terminology

3.1 *Definitions:*

3.1.1 The terminology employed in this guide conforms with industry practice insofar as practicable.

3.1.2 For definitions of general terms used to describe hot cells and hot cell equipment, refer to Terminology C 859, and Guide C 1533.

3.1.3 *bogie*—a bogie is a small cart used to move material, supplies and small tools into, out of and within a hot cell.

3.1.4 *boot*—boot in this context refers to a flexible covering over equipment including a manipulator to protect it from radioactive contamination. The boot may also protect the equipment or manipulator from acid, caustic solutions and abrasive powders.

3.1.5 *Cartesian coordinate system*—a three-dimensional coordinate system in which the coordinates of a point in space are its distances from each of three intersecting, mutually perpendicular, planes along lines parallel to the intersection of the other two. Usually referred to as *X*, *Y*, and *Z*.

3.1.6 *coordinated control*—control of a manipulator that allows multiple axes of the manipulator to be automatically controlled to achieve a special motion of the wrist or end effector. These motions can be straight-line motion of the wrist or end effector, rotation about a point, movement in Cartesian coordinates or other motions at the wrist or end effector requiring relative motion of more than one joint.

3.1.7 *deadhead*—the act of placing a force on an immovable object or component.

3.1.8 *electro-hydraulic manipulator*—a manipulator in which each joint, either rotary or linear, of an electro-hydraulic manipulator is operated by a hydraulic motor or hydraulic cylinder. Control of the flow of hydraulic fluid to the hydraulic motors or cylinders to control position and speed are by electric-controlled servo valves. Electro-hydraulic manipulators are primarily used in under-sea environments and are generally not used in hot cells to date.

3.1.9 *electro-mechanical manipulator*—a manipulator in which each joint, either rotary or linear, of the electro-mechanical manipulator (E/M) is operated by an electric motor or electric actuator. The E/M is usually mounted on a crane bridge, wall, pedestal or ceiling and is used to handle heavy equipment in a hot cell. The E/M is operated remotely using controls from the uncontaminated side of the hot cell.

3.1.10 *end effector*—an end effector is a gripper or other device or tool on the end (wrist) of a slave of a master-slave or power manipulator.

3.1.11 *force ball*—a force ball is an input device in the shape of a sphere that provides signals relative to force and/or torques placed on the ball by an operator. The signals are usually segregated into forces and torques in different directions, usually Cartesian, even though the operator input is generally in a combination of directions.

3.1.12 *force control*—force control is automated control or computer control of a manipulator to maintain a certain force or range of forces on an end effector. Force control requires a sensor to monitor the force or force/torque at the end effector to allow automated or computer control.

3.1.13 *force feedback*—force feedback is an electrical signal relative to force sensed, usually at a joint of a manipulator. Force feedback is commonly used to generate a force at the master that is relative to the sensed force on the end effector.

3.1.14 *force reflection*—force reflection is the perception of force at the master of a master/slave manipulator that is relative to the forces applied at the end effector.

3.1.15 *gray*—the SI unit of absorbed radiation dose. One Gray (Gy) equals 100 Rads.

3.1.16 *hot cell*—a hot cell is 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 several grays or more per hour (hundreds of Rads per hour). See Guide C 1533 for more detail.

3.1.17 *mechanical master-slave manipulator*—a mechanical master-slave (m/s) manipulator is a device used to remotely handle materials in a hot cell. It replicates the actions of an

[4] Available from U.S. Government Printing Office, Superintendent of Documents, Mail Stop SSOP, Washington, DC 20402-9328

[5] Available from American Nuclear Society, 555 North Kensington Ave., La Grange Park, IL 60525, (312) 352-6611

[6] Available from American National Standards Institute, 11 W. 42nd St., 13th Fl., New York, NY 10036

[7] Available from American Society of Mechanical Engineers, 3 Park Ave., New York, NY 10016

[8] Available from International Organization for Standardization (ISO), 1 rue de Verembe, Case postale 56, CH 1211, Geneva 20, Switzerland

[9] Available from Global Engineering Co., 15 Inverness Way, Englewood, CO 80112

[10] Available from National Fire Protection Agency (NFPA), One Batterymarch Park, Quincy, MA 02269

[11] Available from U.S. Government Printing Office, Superintendent of Documents, Mail Stop SSOP, Washington, DC 20402-9328

operator outside the cell with a manipulator in the cell by means of a mechanical connection between the two, usually a metal tape or cable.

3.1.18 *mock up*—an area designated for the testing of hot cell equipment or the process of qualifying said equipment prior to sending it into the hot cell for operation. A mockup is usually equipped with master-slave manipulators and electro-mechanical manipulators and cranes to simulate the hot cell dimensional envelope and operations.

3.1.19 *moused hook*—a moused hook is a lifting hook on a crane that has a latch (mouse) across the mouth of the hook. The latch keeps the cable, bail or other device within the hook so that it can not accidentally slide off of the hook. The latch is manually activated to release the cable, bail or other device from the hook. Moused hooks are not used in hot cells because of the inability to manually release the latch.

3.1.20 *pendant*—a pendant is a box with switches, buttons, other controls and sometimes a small display screen used to control equipment including manipulators and cranes. The pendant usually has a cable or umbilical cord to transmit signals from and to the pendant. Some pendants transmit and receive signals over radio frequencies, so they don't require an umbilical cord.

3.1.21 *power manipulator*—a manipulator with joints activated electrically or hydraulically. See electro-hydraulic manipulator and electro-mechanical manipulator.

3.1.22 *teleoperated control*—teleoperated control is remote control of equipment, including manipulators and cranes by an operator from outside the hot cell or confinement. Teleoperated control is aided by an operator's view of the equipment through a window, periscope or camera/monitor. An operator is always "in-the-loop" in teleoperated control.

3.1.23 *through-the-wall sleeve*—a through-the-wall sleeve is a pipe, open at both ends, embedded in the shield wall of a hot cell into which the manipulator is inserted. A window is generally placed below the sleeve(s) to provide the operator a view of the manipulator(s).

4. Significance and Use

4.1 Materials handling equipment operability and long-term integrity are concerns that originate during the design and fabrication sequences. Such concerns are most efficiently addressed during one or the other of these stages. Equipment operability and integrity can be compromised during handling and installation sequences. For this reason, the subject equipment should be handled and installed under closely controlled and supervised conditions.

4.2 This guide is intended as a supplement to other standards (Section 2, Referenced Documents), and to federal and state regulations, codes, and criteria applicable to the design of equipment intended for this use.

4.3 This guide is intended to be generic and to apply to a wide range of types and configurations of materials handling equipment.

4.4 The term *materials handling equipment* is used herein in a generic sense. It includes manipulators, cranes, carts or bogies, and special equipment for handling tools and material in hot cells.

4.5 This service imposes stringent requirements on the quality and the integrity of the equipment, as follows:

4.5.1 Boots and similar protective covers should not restrict movement of the equipment, should be properly sealed to the equipment and should withstand the radiation, cell atmosphere, dust, cell temperatures, chemical exposures, and cleaning and decontamination reagents, and also resist snags and tearing.

4.5.2 Materials handling equipment should be capable of withstanding rigorous chemical cleaning and decontamination procedures.

4.5.3 Materials handling equipment should be designed and fabricated to remain dimensionally stable throughout its life cycle.

4.5.4 Attention to fabrication tolerances is necessary to allow the proper fit-up between components for the proper installation and mounting of materials handling equipment in hot cells, for example, when parts or components are being replaced. Fabrication tolerances should be controlled to provide sufficiently loose fits where possible to aid in remote maintenance and replacement of equipment and components.

4.5.5 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.

4.5.6 Smooth surface finishes are necessary for decontamination reasons. Irregularities that hide and retain radioactive particulates or other adherent contamination should be eliminated or minimized.

4.6 Materials handling equipment that is exposed to high temperatures, pressures, acidic or caustic conditions may require special design considerations to be compatible with the operating environment. Potential rates of change for temperature and pressure as well as absolute temperature and pressure extremes, created by activation of fire suppression systems and other emergency systems, should be considered.

4.7 When replacing, modifying or adding additional materials handling equipment to an existing hot cell, maintenance records of materials handling equipment in that hot cell or in a hot cell having a similar processing mission may be available for reference. These records may offer valuable insight with regard to the causes, frequency, and type of failure experienced for the type and class of equipment being designed and engineered, so that improvements can be made in the new equipment.

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

5. Quality Assurance and Quality Requirements

5.1 The owner-operator should administer a quality assurance program approved by the agency of jurisdiction. QA programs may be required to comply with 10CFR50 Appendix B, 10CFR830.120 Subpart A, ASME NQA-1, or ISO 9001.

5.2 The owner-operator should require appropriate quality assurance of purchased materials handling equipment and components to assure proper fit up, operation and reliability of the equipment in the hot cell.

6. General Requirements

6.1 *Design Caveat*:

6.1.1 Only the minimum amount of materials handling equipment should be placed in a hot cell to allow safe and efficient operation. Unnecessary materials handling equipment in a cell adds to the cost of operating and maintaining the cell and add to the eventual decontamination and disposal costs of equipment in the cell. A thorough review of the materials handling equipment necessary to perform the hot cell operations should be performed prior to introducing radioactive materials into a new hot cell.

6.1.2 All hot cell equipment should be handled with extreme care using the materials handling equipment during transfer handling and installation sequences to ensure against collision damage.

6.1.3 Installation sequences should be planned and sequenced so that other equipment is not handled above and around previously installed components to the extent practicable.

7. Materials of Construction

7.1 *General Considerations for Metals and Alloys*:

7.1.1 It is desirable that corrosion resistant alloys or metals be used for all material handling equipment in this service. The advantages of corrosion resistant alloys or metals should be considered against their increased cost and availability. Refer to Materials of Construction in Guide C 1533.

7.1.2 In many cases, it is not possible to substitute a corrosion resistant metal for one that isn't corrosion resistant, such as in the case of structural members or commercial components. Consideration should be given to painting those items. Refer to Guide C 1533, 8.2 General Considerations for Paint and Coatings.

7.2 *General Considerations for Plastics and Other Materials*:

7.2.1 Plastics, elastomers, oils, grease, resins, bonding agents, solid-state devices, wire insulation, thermal insulation materials, paints, coatings, and other materials are subject to radiation damage and possible abrupt failure. Not all such materials and components can be excluded from service in the subject environment. Their use should be carefully considered. Refer to Guide C 1533, 8.3 General Considerations for Nonmetallic Materials.

8. Equipment

8.1 Materials handling equipment should be designed or modified in a way that will extend the service life of the equipment, reduce failures, and improve maintainability. The installation position, the orientation, and the attachment methods should be such as to simplify removal and replacement of mechanical equipment susceptible to periodic or unpredictable failure or outage.

9. Mechanical Equipment

9.1 Specific mechanical equipment is covered in Section 11 of this standard guide.

10. Instrumentation

10.1 Where practical and beneficial, equipment used for handling nuclear and radioactive materials should be equipped with instrument sensor components, circuitry, readout, control, and alarm elements that allow continuous and precise monitoring and control of the material handling operation.

11. Materials and Equipment Handling/Transport Facilities

11.1 *General*:

11.1.1 Safeguards and procedures should be used with hot cell material handling equipment to avoid nuclear criticality. See ANS 8.1.

11.1.2 Manipulators and cranes, like other hot cell equipment, are subject to radiation damage effects and contamination. Since decontamination and maintenance work is generally carried out remotely or by personnel working in anti-contamination clothing with respiratory protection, the work is tedious, awkward, and time consuming, which can produce significant radiation dose. The materials handling equipment covered in this section should be designed and fabricated to accommodate fast, simple cleanup routines, so that component repair or changeout procedures are simplified. In addition, the use of wash-down rated components should be considered.

11.1.3 Where practicable, crane and manipulator components should be modular in design. In the case of cranes, the hoist motor should be designed to be easily removable from the trolley so that it can be repaired in an area with lower radiation fields. The incell portion of the master/slave manipulators should be also be removable so that they can be repaired in a glovebox with lower radiation fields.

11.1.4 Through-the-wall manipulators are operated by means of a direct mechanical linkage between the master and the slave ends. They are operated from behind a shield wall or confinement barrier. Since part of the manipulator is outside the cell, this type of manipulator does not come under the strict definition of "equipment mounted in the hot cell environment," however, this type of manipulator is included in the scope of this guide.

11.1.5 Reliance on the use of master-slave manipulators or any other type of manipulator to bring about or maintain a safe condition in the hot cell is not recommended. This requires having an operable manipulator available on a full-time basis. Manipulators should not be used under conditions that would require their use to initiate, execute, or control equipment or operations that are vital to the safe operation of the facilities in the hot cell.

11.1.6 Electrical design constraints and precautions or suggestions related to viewing capabilities for materials handling equipment as covered in subsequent sections are generally applicable to either a crane or a carriage-mounted manipulator installation.

11.1.7 The use of limit switches and bumpers provides the means of setting limits for the movement of materials handling system components.

11.1.8 Computer program instructions incorporated in the crane or manipulator control system are another means of limiting the movement of materials handling system components. Crane hooks or manipulator arms can be excluded from areas where collisions with or damage to other equipment may occur. The ability to override such pre-programmed limits should be provided, but only under controlled and supervised conditions. Software limits are not as reliable as hard stops, and are generally incorporated in addition to hard stops to prevent routine use of the hard stops.

11.1.9 For information and references on pneumatic and hydraulic systems, see Guide C 1533.

11.2 *Mechanical Master-Slave Manipulators*:

11.2.1 Mechanical master-slave manipulators are operated by means of a direct mechanical linkage between the master and the slave ends. They are operated from behind a shield wall or confinement barrier. Note that these manipulators can be removed for maintenance or, when required, replaced in their entirety except for the through-the-wall sleeves.

11.2.2 Through-the-wall and over-the-wall mechanical master/slave manipulators are usually installed side-by-side as a set of two. Multiple sets of this type of manipulator are used to obtain the volumetric coverage required in large hot cells. These manipulators are suited to dexterous handling operations in experimental and laboratory facilities that cannot be accomplished in any other fashion. They are often used in conjunction with batch processing operations involving nuclear or radioactive materials in particulate, granular, or solid form, or when processing steps are conducted in small scale equipment and the process requires physical handling and transfer operations. Because of their dexterity, mechanical master/slave manipulators are also used in large process cells for handling operations, operation and maintenance of in-cell equipment and in handling rigging for in-cell cranes. These manipulators inherently provide some degree of force and torque feedback to the operator. Depending on operator proficiency, these manipulators can be used to perform complex, delicate and precise material handling operations.

11.2.3 Mechanical master/slave manipulators typically use metal tapes or cables to link the master to the slave. The tapes and cables can have long life, but can fail due to fatigue after extended usage, or may fail prematurely due to misuse. Misuse is commonly lifting loads above their rating or shock loads due to collisions or hammering.

11.2.4 Mechanical master-slave manipulators generally have a payload of approximately 20 pounds when fully extended, although heavy-duty units capable of up to 100 pounds are available. Capacities for all manipulators are dependent on the angle of the manipulator while lifting an object. The rated lifting capacity and reach of the master-slave manipulator are important considerations when selecting the type of manipulator for a specific hot cell application.

11.2.5 Mechanical master/slave manipulators have grippers or end effectors with a fixed size and maximum opening. Components in the cell to be manipulated should be compatible with the grippers. See Fig. 1 for an example of one type of gripper dimensions.

11.2.6 Mechanical master-slave manipulators should be installed in pairs to provide maximum handling dexterity, although single manipulators are occasionally used for specific tasks. An operator may use the pair or two operators can cooperate in operations where each operates one manipulator.

11.2.7 Boots or sleeves are available for most mechanical master/slave manipulators. These boots cover the slave arm in order to minimize the contamination on the assembly extending into the hot cell. In dirty, dusty environments boots can keep material out of the manipulator bearings, gears and pulleys, thereby extending time between maintenance and repair. However, the boots can be a nuisance due to their size, weight and restrictions to movement, and can be ripped or torn in operation. Therefore, the use of boots should be considered on a case-by-case basis. In hot cells contaminated with alpha emitting radionuclides, boots are recommended.

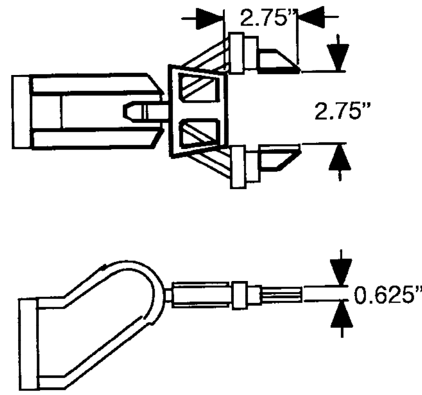

FIG. 1 Typical Gripper Dimensions

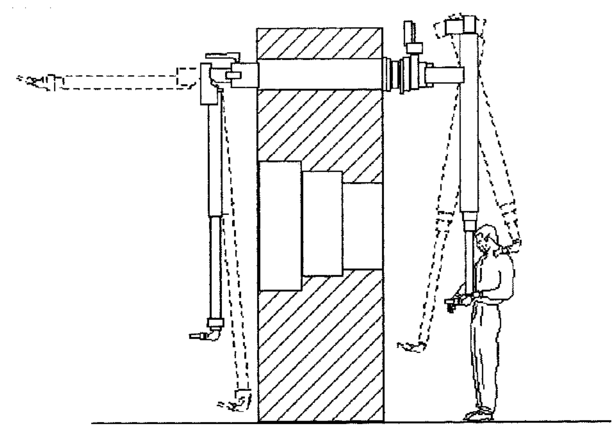
FIG. 2 Typical Mechanical Master-Slave Manipulator

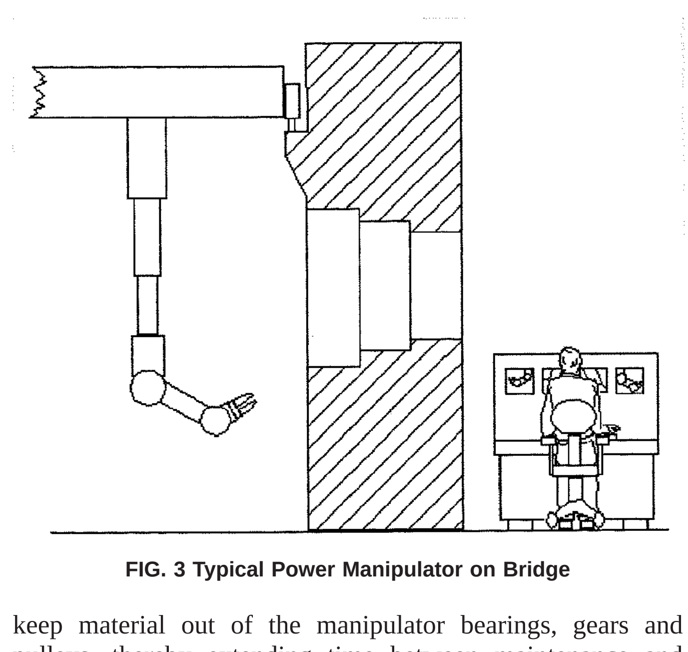
FIG. 3 Typical Power Manipulator on Bridge

11.3 *Power Manipulators*:

11.3.1 Both electric and hydraulic power manipulators are available for service in hot cells. Hydraulic manipulators have been used in radiation environments for short duration applications, but generally are not used for long-term applications. If the hydraulic power pack is located outside the cell, there is concern over potentially contaminated hydraulic fluid, under pressure, being re-circulated outside the cell. The hydraulic power pack is generally not located inside the cell due to the complexity of this equipment and the attendant maintenance and repair of the power pack inside the cell. Since almost all long-term power manipulators used in nuclear service to date are electric, only electric power manipulators are discussed in this guide.

11.3.2 Due to the force they can exert and the speeds at which they can move, power manipulators have the capability to inflict damage in a cell. This potential damage may be to other equipment in the cell and also cell windows. Abrupt physical contact of a manipulator with an internal window surface could result in a cover glass or glass pane fissure or dielectric discharge. This potential damage to cell windows and equipment can be prevented by limiting the speed of travel, by including slip clutches in drive systems, by placing physical limitations on the work envelope, by providing adequate guards on the equipment or windows, or by using software algorithms that limit the motions of travel.

11.3.3 Power manipulators can have much higher load lifting capacity than mechanical master-slave manipulators. Capacities to lift several hundred pounds are typical. Because the mechanical linkage between the master and slave is not required, the slave can be fixed in any suitable location in the cell or placed on a bridge or carriage to change the slave location in the cell. The master can also be located at a window to allow direct viewing or in any location when video systems are provided.

11.3.4 Electric power manipulators can have only tele-operation capabilities or can have tele-operation capabilities augmented with robotic capabilities. Electric power manipulators with robotic capabilities can have operational advantages over manipulators with only tele-operation because of the coordination of degrees of motion and ease of control. However, manipulators with robotic capabilities require additional components to feed back position and velocity. Therefore, they are more complex, which generally reduces reliability. If designed properly, the manipulators may be operated without feedback (teleoperated) if feedback is lost. The feedback of signals also means that bus bars, if used for power, must be augmented with other means to feedback signals. The operational advantages of robotic capabilities must be weighed against the additional cost, complexity and potentially lower reliability.

11.3.5 Contemporary electric power manipulators are available with coordinated control. Even a push button control, usually on a pendant, can provide straight-line motion relative to the cell coordinates (world) or relative to the wrist (tool). These manipulators can also have hand controls, e.g. joysticks and force balls, that can simplify coordination of multiple joints and can also provide straight-line motion in world or tool coordinates. With coordinated control, other options are also available including setting a maximum speed and rotating about a point. Some power manipulators use a replicate master for control. This provides operation similar to a mechanical master, but does not provide force reflection.

11.3.6 Provision should be made to remotely remove a manipulator for repair or replacement if the manipulator fails with the joint(s) in any position. An alternative is to provide a means for moving a joint by mechanical means in the event of a failure. However, this alternative should be available with all failures including a condition that prevents the axis motor or reducer from turning, or in the case of a failed coupling or shaft.

11.3.7 Force feedback has been provided on some power manipulators. The intent of force feedback is to provide the operator with a “feel” of the task, similar to that provided with normal manual tasks and to that provided with a mechanical master-slave manipulator. Also, force feedback would indicate unintended contact with other equipment or material in the cell and allow the operator to respond appropriately. The ratio and fidelity of the force feedback is critical. Results of the use of force feedback on power manipulators have been mixed. Some results indicate the ability to accomplish more dexterous tasks, such as threading a nut on a screw, and more efficient (faster) task completion. Other results indicate only marginal dexterity increases coupled with a much more complex and, therefore, less reliable system.

11.3.8 Power manipulators with six degrees of freedom in a proper configuration will allow placement of the gripper or end-effector in any position in the manipulator’s work envelope and in any orientation. Power manipulators with fewer than six degrees of freedom may be acceptable for certain applications, but their inability to present the gripper or end-effector in any orientation, or with some configurations in any position, should be completely understood and accepted. Power manipulators on tracks or carriages essentially provide additional degrees of freedom, which can significantly increase the work envelope of a manipulator, and also allow approach from different attitudes, thereby increasing flexibility. The redundancies that these additional degrees of freedom add should be controlled and handled appropriately.

11.3.9 *Fixed Power Manipulators*:

11.3.9.1 Fixed, electric, power manipulators may be mounted on the cell floor or cell walls. They are generally not mounted on cell ceilings due to interference with bridge cranes and the incompatibility with cell covers.

11.3.9.2 Fixed, electric, power manipulators should have power and instrument cables that are designed to be remotely replaceable. The cables should be mounted in such a way that they cannot be contacted or damaged by the manipulator.

11.3.9.3 An alternate to cables in the cell is a power manipulator attached to a through-the-wall tube which contains the cables. This extends cable life, since the cables are not exposed to as much radiation and the cell environment. This also makes cable replacement easier and faster.

11.3.10 *Carriage-Mounted Manipulators*:

11.3.10.1 Carriage-mounted, electric, power manipulators have the advantages of providing a much larger work envelope for the manipulator and allowing single-axis, straight-line motion along the carriage axis. Carriage-mounted manipulators are also more complex than fixed manipulators due to the added axes and the requirement for management of moving cables, which can reduce reliability. An alternative for carriage-mounted power manipulators without robotic capability is the use of bus bars instead of cables for power.

11.3.10.2 Carriage-mounted manipulators placed completely inside the hot cell on either a floor-mount, wall-mount or an overhead-mount carriage configuration have been used in specialized situations. Such maneuverable manipulator assemblies have been used in specially equipped cells to maintain and repair other equipment under high radiation exposure conditions. This is one example of an installation where their use may be warranted, provided an overhead crane is also supplied to retrieve the manipulator and its carriage or trolley in their entirety.

11.3.10.3 The use of paired, carriage-mounted manipulators under conditions that call for the use of one or a pair of manipulator arms to effect maintenance and repair operations on another manipulator arm in order to have a hot cell facility remain operable is only conditionally acceptable. To be acceptable, in-process radiation sources would have to be removed from the cell or placed in shielded locations by means separate and independent of manipulator usage since the worse case failure scenario would prohibit manipulator access to such sources even with paired manipulator installations. Residual (background) radiation levels in the hot cell (after removal of or shielding of in-process radiation sources) should be low enough to permit maintenance personnel to enter the cell to effect emergency repairs and replacement of failed elements or assemblies. This arrangement has been used in maintenance and decontamination cells where human entry is permissible.

11.3.10.4 Where cables are used, cable management for carriage-mounted manipulators is very important. The cables will flex during use of the carriage and they should not become pinched, be bent in too tight a radius, become tangled or become hung up on the manipulator, obstacles, other equipment or objects in the cell.

11.4 *Cranes*:

11.4.1 Cranes should be designed and built in general conformity with ANSI/ASME NOG-1. That standard is primarily intended to cover cranes in service in nuclear power installations. Thus, many of its provisions are not applicable to hot cell service. Detailed supplementary specifications are required to assure acquisition of an overhead crane adapted to this service. Cranes should also be designed and built in general conformity to ANSI B30.2. OSHA 29CFR1910 states that "all overhead and gantry cranes constructed and installed on or after August 31, 1971, shall meet the design specifications of the ANSI Safety Code for Overhead and Gantry Cranes, ANSI B30.2."

11.4.2 All crane components susceptible to radiation damage should be shielded and placed in locations on the crane where radiation exposure is minimized.

11.4.3 Mechanical components should be placed in sealed enclosures, to the extent practicable, to prevent particulates and vapors from collecting on surfaces that require periodic maintenance and servicing, particularly bearings, gear boxes, shaft pillow blocks, hoist assemblies, brake assemblies, and all of the electrical components.

11.4.4 A remotely operable cable cutter assembly should be considered on the main crane hoist cable assembly, and any cable for any hoist having a rated capacity in excess of five tons. The cable cutter(s) should be capable of severing all of the cable strands so as to unload the hoist assembly in the event of a failure scenario that offers no alternative method or scheme for returning the crane to its maintenance and servicing location (in the hot cell crane maintenance area).

11.4.5 In cases where the crane cannot be removed remotely, the crane should be equipped with an air-operated or alternative type of emergency drive assembly, independent of the crane power supply, in order to permit the crane to be returned to the maintenance area in the event of total loss of electrical power, or a mechanical failure that immobilizes the crane. Redundant drive motors may be considered, but should be able to move the crane with a reasonable single failure, for example, a wheel bearing seizing.

11.4.6 The use of hydraulically actuated systems or components should be minimized. Hydraulic systems, when supplied, should be leak-tight for the specific fluid used and equipped with a hand pump backup to the motorized pump. Piping should be Type 304L stainless steel with welded fittings, except for the connections at points requiring periodic inspection, and unions provided to effect quick component changeout. Hydraulic actuators may have to be exercised on a routine basis to maintain the seals. Non-hazardous and non-flammable fluids are available and should be considered for the specific hot cell application, Radiation resistance of seals should be considered. Criticality of hydrogenous fluid may also be a concern in certain applications. Non-hydrogenous hydraulic fluid is available.

11.4.7 All crane hoists having a lift capacity in excess of one ton should have two independent hoist braking systems. Both braking systems should be fail-safe with respect to holding any load suspended/hanging on the hoist hook. The brakes should have provisions for controlled release and lowering of the load(s) under emergency power outage/failure conditions.

11.4.8 Axle/wheel design should allow for shaft replacement in the event of a catastrophic bearing failure. Crane axles should be of the rotating type. Wheel/axle disassembly should not require use of a hydraulic press.

11.4.9 The crane wheels and the alignment provisions for the wheels should be readily accessible for purposes of maintenance. Alignment provisions are required for each wheel, on a separate wheel-by-wheel basis. These provisions should accommodate adjustment in three planes and have lock-down features to preserve wheel alignment. The crane should track on the rails accurately without excessive "flanging." Wheels should not climb the rails and derail.

11.4.10 Jack-down idler wheels should be provided at each end truck position for use as an emergency backup in the event of wheel bearing failure or wheel fracture. The jack-down mechanisms for such wheels should be accessible or remotely operable under predicated failure scenarios. Multiple wheels may be considered as an alternate.

11.4.11 Crane (or manipulator carriage) and main hoist trolley wheels should have treads that have been hardened to an appropriate level. Wheels at each end of the crane should be driven so that a front wheel drive configuration is maintained regardless of crane travel direction. Drive wheels on each end of the bridge and hoist trolley should be machined to have matching diameters to provide parallel tracking of the end trucks.

11.4.12 The total crane assembly should be designed, manufactured, and installed so that the crane cannot fall into the hot cell under any credible failure scenario, barring violent acts of nature that distort the building structure. Seismic restraint devices for rail-mounted equipment should be considered. The crane design should be subjected to seismic analysis and qualification.

11.4.13 The crane's main hoist trolley should be designed and configured to remain on the crane bridge under expected and predictable failure scenarios and seismic events.

11.4.14 Cranes designed to be maintained while remaining on the rails in a crane maintenance area should have a working walkway platform extending the length of the crane, along both sides of the crane carriage, with protective railings on both sides of the platforms. Step or ladder access to the walkways should be provided, meeting AAI A14.3, ASSE SA/SAFE, 29CFR1910, and ANSI B30.2 standards. The access should be available from any crane position in the crane maintenance area. The working (or access) platforms should be positioned to permit access to all components requiring periodic inspection and/or maintenance by personnel suited in anti-contamination clothing. The working platforms should not be placed or constructed in a fashion that will hinder or obstruct decontamination sequences on any portion of the crane.

11.4.15 All hoists should be configured to provide a plumb lift.

11.4.16 Moused hooks are not used in hot cells due to inability to manually operate the mouse. This imposes additional responsibility to not allow loads to be removed from the hook unintentionally.

11.4.17 Maintenance on hot cell cranes should be performed in a shielded "crane maintenance" area at one end of the crane runway or an additional crane or hoist may be required to remove the hot cell crane from the rails or bridge for transfer to an acceptable maintenance area.

11.4.18 *Crane Proof Testing*:

11.4.18.1 A proof test should be performed on all remote cranes after installation and before the facility goes into radioactive operation. Cranes that are to be installed in an existing facility already in radioactive operation, should have a proof test performed at a vendor facility or on-site, before installation. A proof test should be performed, if practical, to test function and capacity of replaced components. Refer to ASME B30.2 for additional information regarding proof testing of newly installed cranes.

11.4.18.2 A proof test consists of loading the applicable hoisting equipment to its full capacity to insure the integrity of the installation and its load bearing components. Proof testing should be no less than 100 % and no more than 125 % of the rated working load limit of the equipment or as directed by the equipment manufacturer. An initial proof test and inspection of all new, repaired, modified, or replaced hoisting and rigging equipment should be performed prior to the equipment being transferred into a contaminated area. In the case of new construction the equipment should be proof tested and inspected prior to its initial use and before the area is contaminated. If possible, new, repaired or replaced load bearing components should be tested and inspected prior to installation (for example, pre-certified hoist cable). This in combination with a post maintenance functional test may take place of an in-place proof test.

11.4.18.3 If in-place proof testing is necessary then considerations should be made for the appropriate equipment. An example would be the installation of a deadhead for use with a remotely readable load indicating device or a pre-certified test weight. Testing should be done in an area where failure would not result in damage to the facility, other equipment, or personnel.

11.4.18.4 Test weights should be certified accurate within −5 % and +0 % of the required weight. Test weights should have engineered pick points to minimize unnecessary rigging. Test weights should be configured to minimize storage requirements when maintained in the hostile environment. Test weights that will not be stored in the hostile environment should have an exterior surface that is easily decontaminated. Test weights should not be fabricated from materials that will create Resource Conservation and Recovery Act (RCRA) regulated wastes when discarded. See 40CFR 260-279 Solid Waste Regulations. Test weights should be labeled with the actual weight, preferably with weld bead of appropriate height.

11.4.18.5 Prior to placing equipment back in service after proof testing it should be inspected to insure that a failure has not occurred during the course of the testing. A trained and qualified individual should inspect load-bearing components. Remote viewing equipment should be used where necessary to inspect areas inaccessible by direct viewing. In addition, functional testing without a load should be performed prior to placing equipment in service.

11.4.18.6 Inspection and proof testing documents should be retained for the life of the equipment.

11.4.19 *Other Crane Testing*:

11.4.19.1 The hoist brake(s) should be tested both with a static load and a dynamic load. For safety, these tests should be conducted with the load very close to the floor. During the static load test, the power to the crane should be disconnected and reconnected to assure proper brake operation with a loss of power.

11.4.19.2 The trip setting of hoist limit devices should be determined by tests, with an empty hook traveling at increasing speeds up to the maximum speed. The actuating mechanism of the limit device should be located so that it will trip the device, under all conditions, in sufficient time to prevent contact of the hook or load block with any part of the trolley or crane.

11.4.19.3 The trip setting of the bridge and trolley travel limits should be determined by tests, with an empty hook traveling at increasing speeds up to the maximum speed. The actuating mechanism of the limit device should be located so that it will stop the bridge and trolley, under all load and speed conditions, in sufficient time to prevent contact with fixed stops.

11.4.19.4 The overload protection device should be tested to assure that the hoist motor will be shut down if the crane rated load is exceeded. This overload protection device must be temporarily disabled for a proof test of more than 100 % of rated load.

11.5 *Electrical Design Considerations*:

11.5.1 All electrical motors, starters, circuit breakers, transformers, fuses, and other circuit elements should be totally enclosed and waterproof. Explosion proof elements may be required under certain circumstances.

11.5.2 All wound rotor motors should be rated for 60 hertz, continuous crane duty. Induction motors should be rated for continuous duty.

11.5.3 Brushless motors, whether ac or dc, should be considered for maintenance reduction. If brushed motors are used, Grade 660 carbon brushes can provide extended wear.

11.5.4 Electrical power supply and control wiring should meet NFPA 70 and NEMA 250 (Type 4) requirements. Wiring should be totally enclosed in rigid (where feasible) stainless steel conduit, and be continuous between switches, junction boxes, motors, panels, and other elements of the system. Access to wiring junctions, as required, should be made through use of water and vapor proof junction boxes.

11.5.5 All wiring in the control enclosure and between control enclosures and electrical components should be 600V No. 14 AWG minimum, insulated 90°C copper conductors. Smaller gauge wire may be preferable where flexing is required. Electrical insulation on wiring or cable should remain functionally operable up to a cumulative radiation dosage of 1×10^6 grays (1×10^8 rads) where possible and appropriate.

11.5.6 Wiring insulation should not release toxic or corrosive fumes at temperatures under 230°C.

11.5.7 All of the electrical and control gear should be housed in a control room-type enclosure to the extent practicable. The enclosures should be air conditioned and built for ease of cleanup and decontamination. The enclosure should be sized to allow sufficient headroom and clearances for maintenance personnel to enter, walk and work inside the enclosure while effecting electrical and controls circuitry maintenance and repair procedures. The shielding provided for this control room enclosure should limit personnel radiation exposure to the levels applicable under continuous occupancy conditions where possible and feasible.

11.5.8 Bus bars and brushes can be used to provide power to the crane bridge or carriage. They can provide a simple and reliable method for power transmission. However, bus bars and brushes are not generally used for low voltage signal transmission.

11.5.9 Festooned cable can be used to provide power, control and instrument signals to the crane bridge or carriage. The design should prevent the cables from becoming pinched, being bent in too tight a radius, becoming tangled or being hung up on obstacles, other equipment or objects in the cell. Festooned cables may be used for very long runs.

11.5.10 Hinged cable trays prevent cables from becoming pinched, being bent in too tight a radius, becoming tangled or being hung up on obstacles, other equipment or objects in the cell. However, replacement of cables may be more difficult in remote facilities and should be addressed. Hinged cable trays generally are limited to shorter runs than festooned cable.

11.5.11 Cable reels may be considered for providing power and signal transmission. Cable reels used for signal transmission must be carefully designed to consider the quality of signal transmission and potential interference initially and over time. When power and signals are transmitted on the same cable reel, signal interference must be carefully considered. The possibility and results of cable reels malfunctioning (not extending or not retracting) must be considered. Cable replacement on remote cranes must also be considered.

11.5.12 Control signals may be sent wireless over radio frequency. Leaky coax is coaxial cable that has a split shield or other feature to allow a small proportion of the signal to "leak" across the shield. Leaky coax can be used to transmit these radio signals to appropriate antenna(ae) on the bridge in close proximity to the leaky coax. The reliability of the transmitting and receiving components and the antenna system should be proven under prototype conditions before this type of system is accepted.

11.5.13 Coaxial (coax) cable and fiber optic cable can be used for signal transmission. These cables can be festooned or placed in hinged cable trays provided minimum bending radius is maintained. Keeping bending radius well above the minimum will generally increase lifetime. The degradation and subsequent signal attenuation due to radiation exposure of fiber optic cable must be considered in hot cell applications.

11.5.14 The crane control system should constantly verify the integrity of the communications link, if applicable. Crane controls are often linked together with CCTV system controls. Errors in signal data transmission, communications channel noise, and equipment dropouts should not cause any improper or unintended controls system action. Crane or manipulator movements should not result from an improper signal.

11.6 *Lighting and Viewing*:

11.6.1 The use of hot cell materials handling equipment generally requires remote viewing. Direct-view, through-cell-wall windows require high level (very bright) illumination. See ANS Design Guides for Radioactive Material Handling Facilities & Equipment. Concurrent availability of cell windows as well as a video camera monitoring system or equivalent viewing capabilities is recommended. Any such equipment has to be usable any time the materials handling equipment is being operated. The viewing system(s) should provide angles of viewing to allow proper and efficient operation in the cell.

11.6.2 Video camera systems, also called closed circuit television (CCTV) systems, should be radiation hardened, where required, for proper operation in the maximum radiation field expected and for reasonable life with the total radiation dose expected.

11.6.3 Placement of video camera systems and lighting systems to minimize hostile environmental exposures, e.g., in lower dose locations in the cell, should be considered to extend life.

11.6.4 Video camera systems, also called closed circuit television (CCTV) systems, used on or in conjunction with hot cell cranes or carriage-mounted manipulator installations, are usually equipped with camera on/off controls, plus lens focus, lens iris, zoom, and pan/tilt controls.

11.6.5 At least one video camera system used in a hot cell should be mounted in a position such as to provide overall in-cell viewing capability for monitoring the crane or carriage-mounted manipulator movements in order to avoid collisions with other in-cell equipment and piping. Multiple cameras mounted at different locations should be positioned to observe specific areas from different angles to provide depth perception and unobstructed views. The capability of viewing crane hooks and manipulator arm movements is particularly important. At least two independent viewing systems, mounted to provide different viewing angles, should be provided. Radiation shielding windows in the shield wall are often provided for visual monitoring capabilities. Stereo vision systems are available, but user comfort using these systems for extended periods of time must be fully understood before implementation.

11.6.6 Auxiliary high intensity lighting should be mounted to provide viewing illumination for the use of windows, periscope viewing or video camera systems. The actual intensity of the lighting necessary will depend on the cell reflection characteristics, as well as window transmission, periscope lens and video camera lens quality. Both the video camera system components and lighting elements should be fully accessible for maintenance and replacement under the maintenance conditions that prevail for the facility.

11.6.7 Windows usually require higher intensity lighting than cameras for viewing inside the hot cell because of the light diffusion through the windows.

11.6.8 For additional information and references to hot cell lighting and viewing, see Guide C 1533 and ANS Design Guides for Radioactive Material Handling Facilities & Equipment.

11.7 *Installation of Materials Handling Equipment*:

11.7.1 Materials handling equipment received on-site and stored while awaiting installation in the cell or canyon environment should be stored under conditions that prevent heat, moisture, or corrosive damage. The equipment should also be stored under conditions that protect it from damage caused by transfer handling, dropped loads, flying debris, or vandalism.

11.7.2 Installation of materials handling equipment such as cranes and carriage-mounted manipulator systems should be accomplished under closely controlled and supervised conditions to guard against damage to functional components. Complete functional testing should be carried out at the crane manufacturer's site and again on-site (at the final user's site) before installation in the hot cell environment. Tests should include a pressurized cleaning and decontamination cycle to verify water tightness requirements are met.

11.7.3 Crane bridge, trolley and hoist tracking and alignment functions should be completed and locked in place prior to installation, then rechecked and realigned as necessary after installation.

11.8 *Carts and Bogies*:

11.8.1 Small carts or bogies are sometimes used to transfer items between workstations in a hot cell. The cart rides on a rail next to the cell walls within reach of the master-slave manipulators. The cart is electrically driven by small motors powered and controlled through a bus-bar system. Controls in the operating corridor enable an operator to remotely send and retrieve the cart to and from any hot cell workstation. The carts are designed to be removable for repairs.

11.8.2 Design considerations for a successful cart system include features to prevent the cart from derailing in the event of a blockage on the rails, procedures and training to prevent items from falling onto and blocking the rails, the ability to view the rails to ensure that they are not blocked, and features to prevent cross contamination between workstations as the cart moves from one zone to another.

12. Keywords

12.1 crane; design; equipment; hot cells; manipulator; materials handling; nuclear materials; remote handling