INTERNATIONAL

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Standard Guide for Mechanical Drive Systems for Remote Operation in Hot Cell Facilities[1]

This standard is issued under the fixed designation C 1615; 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 standard is to provide general guidelines for the design, selection, quality assurance, installation, operation, and maintenance of mechanical drive systems used in remote hot cell environments. The term mechanical drive systems used herein, encompasses all individual components used for imparting motion to equipment systems, subsystems, assemblies, and other components. It also includes complete positioning systems and individual units that provide motive power and any position indicators necessary to monitor the motion.

1.2 *Applicability*:

1.2.1 This standard 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, for example, without radiation shielding windows, periscopes, or a video monitoring system.

1.2.2 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 ASTM/IEEE SI-10 Standard for Use of International System of Units.

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 mechanical drive systems 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 or state regulations, or both, and codes applicable to equipment under any conditions.

1.3.3 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 which may be applicable in whole or in part to the design, selection, quality insurance, installation, operation, and maintenance of equipment are referenced throughout this standard and include the following:

2.2 *ASTM Standards:* [2]

ASTM/IEEE SI-10 Standard for Use of the International System of Units

C 859 Terminology Relating to Nuclear Materials

C 1533 Standard Guide for General Design Considerations for Hot Cell Equipment

C 1554 Materials Handling Equipment for Hot Cells

C 1572 Standard Guide for Dry Lead Glass and Oil-Filled Lead Glass Radiation Shielding Window Components for Remotely Operated Facilities

E 170 Standard Terminology Relating to Radiation Measurement and Dosimetry

2.3 *Other Standards:*

NEMA MG1 Motors and Generators[3]

AGMA 390.0 American Gear Manufacturers Association, Gear Handbook[4]

[1] This standard is under the jurisdiction of ASTM Committee C26 on Nuclear Fuel Cycle and is the direct responsibility of Subcommittee C26.14 on Remote Systems. Current edition approved Jan. 1, 2005. Published February 2005.

[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] Available from NEMA, 1300 N. 17th Street, Suite 1847, Rosslyn, VA 22209.

[4] Available from AGMA, 500 Montgomery Street, Suite 350, Alexandria, VA 22314-1581.

ANS Design Guides for Radioactive Material Handling Facilities and Equipment, ISBN # 0-89448-554-7[5]
ASME B17.1 Keys and Keyseats[6]
NLGI American Standard Classification of Lubricating Grease[7]
ASME NOG-1 American Society of Mechanical Engineers Committee on Cranes for Nuclear Facilities – Rules for Construction of Overhead and Gantry Cranes[6]
ANSI/ASME NQA-1 Quality Assurance Requirements for Nuclear Facility Applications[8]
ANSI/ISO/ASQ Q9001 Quality Management Standard Requirements[8]
NCRP Report No. 82, SI Units in Radiation Protection and Measurements[9]
ICRU Report 10b Physical Aspects of Irradiation[10]
CERN 70-5 Effects of Radiation on Materials and Components[11]

2.4 *Federal Standards and Regulations:*[12]
40CFR 260-279 Solid Waste Regulations – Resource Conservation and Recovery Act (RCRA)
10CFR 830.120, Subpart A, Nuclear Safety Management Quality Assurance Requirements

3. Terminology

3.1 *General Considerations:*

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

3.1.2 For definitions of general terms used to describe nuclear materials, hot cells, and hot cell equipment, refer to Terminology, ASTM C 859, and ASTM E 170.

3.2 *Definitions:*

3.2.1 *absorbed dose*—the quotient of the mean energy (E) imparted by ionizing radiation to matter of mass (M). The SI unit for absorbed dose is the gray, defined as 1 joule/kg and is equivalent to 100 rads. **NCRP-82 E 170**

3.2.2 *activity*—activity is the measure of the rate of spontaneous nuclear transformations of a radioactive material. The SI unit for activity is the becquerel, defined as 1 transformation per second. The original unit for activity was the curie (Ci), defined as 3.7×10^{10} transformations per second. **NCRP-82**

3.2.3 *alpha*—see radiation

3.2.4 *becquerel (Bq)*—see activity

3.2.5 *beta*—see radiation

3.2.6 *dose equivalent*—represents a quantity used for radiation protection purposes that expresses on a common scale, the dose from all types of radiation. Dose equivalent is the product of absorbed dose (D), a quality factor that normalizes the effects between different radiation types (Q) and other modifying factors (N). The specialized unit for dose equivalent is the rem. The quality factors are specified by the International Commission on Radiological Units and Measurements for different types of radiation and organ exposures. 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} rem. 10 μSv is equal to 1 mrem. **NCRP-82 ICRU –10b**

3.2.7 *encoders*—for the purpose of this standard, are measuring devices that detect changes in rotary or linear motion, direction of movement, and relative position by producing electrical signals using sensors and an optical disk.

3.2.8 *gamma*—see radiation

3.2.9 *gray (Gy)*—see absorbed dose

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

3.2.11 *inert gas*—a type of commercial grade moisture free gas, usually argon or nitrogen that is present in the hot cell.

3.2.12 *linear variable differential transformer (LVDT)*—a transducer for linear displacement measurement that converts mechanical motion into an electrical signal that can be metered, recorded, or transmitted.

3.2.13 *master-slave manipulator*—a device used to remotely handle radioactively contaminated items, or nuclear material in a hot cell. The uncontaminated or "clean" portion of the manipulator is called the "master" and the contaminated portion of the manipulator or follower is called the "slave". Mechanical master-slave manipulators are mounted through the wall of the hot cell or pass through the ceiling. **C 1554**

3.2.14 *mechanical drive systems*—refers to but is not limited to motors, gears, resolvers, encoders, bearings, couplings, bushings, lubricants, solenoids, shafts, pneumatic cylinders, and lead screws.

3.2.15 *mock-up facility*—an area designed to simulate the handling conditions found in a hot cell facility. Mock-up facilities are generally equipped with master-slave manipulators, overhead cranes, and simulated radiation shielding windows. A mock-up area may be a permanent part of a facility or may be a temporary setup.

3.2.16 *moderator*—materials that slow down fast neutrons via collisions between the neutron and an atomic nucleus. A nucleus' effectiveness as a moderator increases as the mass of the nucleus approaches the mass of the neutron. Thus, hydrogen is the most effective moderator, and other nuclei moderate neutrons with decreasing effectiveness as their mass increases. Nuclei with masses above 20 are normally not considered moderators. Moderator examples include people, water, graphite, oil, solvents, concrete, and polyethylene or other plastics.

3.2.17 *radiation absorbed dose (rad)*—see absorbed dose

3.2.18 *radiation—for purposes of this standard*, is defined as the emission that occurs when a nucleus undergoes radioactive decay. The emitted radiations may include alpha and beta particles, gamma rays, and neutrons. **E 170**

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[5] Available from ANS, 555 North Kensington Avenue, LaGrange Park, Ilinois 60526.

[6] Available from ASME, 22Law Dr., Box 2900, Fairfield, NJ 07007-2900.

[7] Available from NLGI, 4635 Wyondotte Street, Kansas City, MO 64112.

[8] Available from ANSI, 25 W., 43rd St., New York, NY 10036.

[9] Available from National Council of Radiation Protection and Measurements, 7910 Woodmont Avenue, Suite 400, Bethesda, MD 20814-3095

[10] Available from International Commission on Radiation Units and Measurements, Inc., 7910 Woodmont Avenue, Suite 400, Bethesda, MD 20814-3095.

[11] Available from CERN European Organization for Nuclear Research, CH-1211, Geneva 23, Switzerland.

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

(1) alpha – alpha radiation is an alpha particle composed of two protons and two neutrons with a positive charge of plus two. (It is the same as a helium atom with no electrons).

(2) beta – beta radiation is an electron that was generated in the atomic nucleus during decay and has a negative charge of one.

(3) gamma – gamma radiation is high energy, short wavelength electromagnetic radiation and normally accompanies the other forms of particle emissions during radioactive decay. Gamma radiation has no electrical charge.

(4) neutron– neutron radiation results from instability in the atomic nucleus that may be the result of either radioactive instability of the nucleus, interaction of the nucleus with another particle or energy source. Neutrons have an atomic mass slightly heavier than a proton, but have no electrical charge.

3.2.19 *radiation shielding window—for the purpose of this standard*, is an optically transparent instrument that provides a means for viewing into a hot cell, and shields the operator while performing work. A shielding window is generally constructed of an outer metal frame called a housing and is filled with optically polished lead glass slabs that are secured within the lead housing with lead packing. Most shielding windows have cover glasses and trim frames on both viewing ends to seal the window cavity. The shielding windows can be either dry or oil-filled.

3.2.20 *radiation streaming*—a term used to describe unshielded beams of radiation.

3.2.21 *resolvers*—for the purpose of this standard, are rotational position measuring devices that are essentially rotary transformers with secondary windings on the rotor and stator at right angles to the other windings.

3.2.22 *sievert*—see dose equivalent

4. Significance and Use

4.1 Mechanical drive systems operability and long-term integrity are concerns that should be addressed primarily during the design phase; however, problems identified during fabrication and testing should be resolved and the changes in the design documented. 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 standard 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 this use.

4.3 This standard is intended to be generic and to apply to a wide range of types and configurations of mechanical drive systems.

5. Quality Assurance and Quality Requirements

5.1 The vendor and owner-operator of hot cell equipment should have a documented quality assurance program. Hot cell equipment should be designed according to stringent quality assurance requirements and undergo quality control inspections as outlined by the authority having jurisdiction. QA programs may be required to comply with 10CFR830.120 Subpart A, ANSI/ASME NQA-1, or ANSI/ISO/ASQ Q9001.

6. General Requirements

6.1 For safe and efficient operation, a minimum number of mechanical drive system components should be placed in a hot cell. Unnecessary equipment in a cell adds to the cost of operating and maintaining the cell and adds to the eventual decontamination and disposal costs of hot cell equipment. A thorough review of the mechanical drive systems necessary to perform the hot cell operations should be performed prior to introducing the equipment into the hot cell.

6.2 All hot cell equipment should be handled with extreme care during transfers and installation sequences to ensure against collision damage.

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

6.4 Principles of good modular design and standardization should be considered for maintainability of equipment during its design life. Determination should be made early in the design at which level of subassembly the equipment will be disassembled and replaced if necessary. The optimal level is strongly influenced by the estimated maintenance time and associated cell down time costs, radiation exposure to personnel, and disposal costs for the failed subassembly. Design with standardized fasteners and other components to limit the inventory of tools needed for maintenance. Use prudent judgement in the selection of fastening materials to avoid galling problems, especially when using stainless steel fasteners.

6.5 Equipment intended for use in hot cells should be tested and qualified in a mock-up facility prior to installation in the hot cell. **C 1533**

6.6 Where possible, electrical and instrumentation controls, readouts, and alarms for mechanical drive systems should be located outside of the hot cell.

6.7 Consideration should be given to the materials of construction for hot cell equipment and their ultimate disposal per RCRA jurisdiction. **40CFR260-279**

7. Materials of Construction

7.1 Plastics, elastomers, resins, bonding agents, solid state devices, wire insulation, thermal insulation materials, paints, coatings, and other materials are subject to radiation damage and possible failure. Not all such materials and components can be excluded from service in the subject environment. Their use should be carefully considered for their particular application and material qualification testing under expected conditions prior to use should also be considered.

7.2 Alpha and beta irradiation can severely and rapidly damage sensitive components when they are exposed to the radiation source. Special consideration should be given to material selection in applications where the equipment is exposed to alpha or beta radiation.

7.3 The method of replacement, the ease of replacement, and/or the substitution of more radiation resistant materials should be considered for components having materials subject to radiation damage.

7.4 Polytetrafluoroethylene (PTFE) should be avoided since it degrades rapidly in radiation environments.

7.5 Polyetheretherketone is a recommended plastic material for seals, valve seats, and other applications because of its resistance to beta and gamma radiation.

8. Equipment Selection

8.1 *General*:

8.1.1 Mechanical drive system components should be selected based on their operability and reliability in a high radiation or high contamination environment, or be modified in a way that will extend the equipment service life or ease of use. The installation position, the orientation, and the attachment methods should be such as to simplify removal and replacement of mechanical equipment susceptible to periodic maintenance or unpredictable failure.

8.2 *Motors*:

8.2.1 *General*:

8.2.1.1 A variety of motors may be used in a high radiation hot cell environment. More than one type of motor may work for the same application. Motor selection depends on many factors, such as the required speed, torque or horsepower, physical frame size, voltage requirements, enclosure type, mounting requirements, bearing type, service factor, and duty cycle. The longevity of a motor in a hot cell environment depends on several variables such as the hot cell atmosphere, the amount of moisture and corrosive fumes in the atmosphere, the quality of the motor, the materials of construction, and the radiation exposure to the motor.

8.2.1.2 Motors smaller than 10 horsepower are usually pre-lubricated at the factory and will operate for long periods of time under normal service conditions without requiring periodic lubrication. The bearings of larger motors however, may require periodic lubrication using high-quality grease with a consistency suitable for the motor's insulation class. Motors with sealed-for-life lubricated bearings are preferred over motors that require periodic lubrication. Refer to the section on lubrication for lubricants recommended for hot cell applications.

8.2.1.3 Capacitor start, single-phase, alternating current (AC) motors have proven to be reliable in hot cells and are typically less expensive than direct current (DC) motors of equivalent horsepower. Generally, AC motors are also smaller than DC motors for the same horsepower. This can be an advantage in some uses where a larger motor may adversely affect the design. Three-phase induction AC motors are the preferred choice because of their robustness and starting simplicity. In lower radiation areas, i.e., less than 250 mGy/hr (25 rad/hr), an off-the-shelf single phase AC motor usually works well and will typically last for several years.

8.2.1.4 Lower voltage motors are generally preferable to high voltage motors when used in an argon gas environment hot cell. For example, a 240-volt AC three-phase motor is preferred over a 480-volt AC motor because of the potential for arcing at higher voltages particularly inside electrical feed-throughs. However, 208/440-volt AC three-phase motors will often be used in low horsepower applications in place of 110-volt AC single phase motors in order to minimize the required wire size and connector ampacity. Refer to the ANS Design Guide #2 for extensive information regarding hot cell penetration and feed-through design, installation, and testing. **ANS Design Guides ISBN # 0-89448-554-7**

8.2.1.5 Typically, motors with high temperature insulation, type H for example, are better suited to withstand radiation damage than motors with lower temperature rated insulation.

8.2.1.6 Most types of motors may need to be de-rated when used in hot cells with a higher ambient temperature and/or a thermally insulating gas such as argon.

8.2.1.7 Motors used in a hot cell should, where feasible, be similar in make and size in order to reduce the number of spare motors and to standardize on the size and type of electrical connectors and method of control.

8.2.2 *AC and DC Motors*:

8.2.2.1 Both AC and DC motors have been used successfully in air and argon gas atmosphere hot cells. In cases of high purity atmosphere hot cells, motors with brushes may not be acceptable because of the impurities generated from brush wear. Some brushless DC motors contain sensitive electronics that may be susceptible to radiation damage and should be evaluated for their use in high radiation hot cells. Table 1 shows various types of motors and their recommended applications in hot cells.

8.2.3 *Servomotors*:

8.2.3.1 Servomotors are used in situations requiring high accuracy in positioning and speed. Servomotors can be AC, DC brush-type, or brushless DC. Closed-loop servo control systems use feedback devices to provide information to a digital controller, which in turn produces the command signal which drives the motor. Wire-wound resolvers are the preferred method for position and velocity feedback in a hot cell environment for servomotors due to their inherent physical simplicity and the fact that semi-conductors are not required to be in close proximity to the resolvers.

8.2.3.2 Brushless DC servomotors have been used successfully in hot cells because they have the advantage of not having brushes that may wear out over time, but they may have electronic circuits that are susceptible to radiation damage. If the horsepower requirements go beyond 5 hp, an AC motor should be considered.

8.2.3.3 The motor cable length, design, and connector requirements should be to the vendor's recommendations. Problems of motor operation or positioning and/or feedback errors commonly occur if the wiring is beyond the vendor's recommended length.

8.2.4 *Gearmotors*:

8.2.4.1 A gearmotor is an electric motor combined with a geared speed reducer. The geared speed reducer is made of helical, worm, or spur gears used in single or multiple stages. The geared output shaft may be parallel with the motor, or may be at a right angle to the motor.

8.2.4.2 An important consideration when using gearmotors is the type of lubricant used in the gear housing. It may be advisable to supply a preferred lubricant to the gearmotor vendor at the time of purchase to be used in the gearmotor gear housing. Refer to the section on lubrication for hot cell recommended lubricants.

TABLE 1 Motors and Their Recommended Applications for Hot Cells

Type	Horsepower	Typical Size (dia.)	Application	Comments
AC Shaded Pole 115/208-230 VAC	0 -1	3″ – 6″	Fans and blowers	• Inexpensive • Light duty • Simple controller • No position or velocity feedback • Non reversible • Low starting torque • Non-precision positioning • Applications requiring small motors
AC capacitor start, 115 VAC, single phase	½ - Up	6″- Up	Pumps and blowers	• Inexpensive • Fixed speed • Moderate to high starting torques • General purpose motor • High current per horsepower • Light duty
AC Three-phase 208-230 VAC	½ - Up	6″ - Up	pumps, blowers, fans, compressors, agitators, hoists, general purpose motor	• Inexpensive • Reversible • High starting torque • Requires three-phase source • Generally fixed speed, but variable speed can be achieved by using variable freq.drive (VFD)
DC brush (permanent magnet)	1⁄16 - 1	1″ – 8″	Variable speed drives, mixers, conveyors, high torque small gearmotors	• Can be low voltage • Inexpensive motor and controller • Variable speed • No position feedback • Non-precision positioning • Brushes may require replacement with high altitude brushes for longer life
DC Brushless – (permanent magnet/servo)	1⁄32 - 5	1″ - 8″	High torque small gearmotors, robotics, linear actuators	• Compact • Expensive • Precision positioning • Reversible • Velocity control • Can be low voltage • Long life in high radiation fields if the drive electronics are moved out of cell
DC Shunt-Wound	5 - Up	6″ - Up	Larger loads requiring variable speed, direction, and position control	• Variable speed/torque control available • Larger motors operated at low speeds require forced cooling • Limited use
Stepper (Brushless DC)	¼ – ½	3″ - 5″	Robotics	• Consumes power to hold position (heat buildup) • Requires feedback for closed-loop position indication • Requires computer/micro processor control system • Can be operated open-loop • Expensive motor controls
Universal AC or DC	Fractional	3″ - 6″	Power tools and vacuum cleaners	• High torque available in a small motor • Inexpensive • Low efficiency • Brushes may require replacement if motor is used in low moisture or inert gas environment • Normally powered by 120 VAC

8.2.4.3 Some small gearmotors may contain materials that are susceptible to radiation damage and may not be suitable for long term use in a hot cell.

8.2.5 *Brakemotors*:

8.2.5.1 A brakemotor is an electric motor connected to a spring-set brake. In the event of a power failure, the brake stops the motor and holds the load in position. When the motor is operated, electric current is applied to the brake, releasing the set. Brakemotors are commonly used on hoists or other lifting devices. The electronics for brakemotors should be removed from the brakemotors before installation and placed in a non-radiation area. In the event that a brake does not release, careful consideration must be given to the proper method for supporting the load while the brake is repaired or replaced.

8.2.6 *Stepper Motor*:

8.2.6.1 A stepper motor operates by rotating a shaft in incremental steps. Electrical pulses are supplied to the motor using a translator drive or indexer. The motor converts the digital signals into fixed mechanical increments of motion. This allows the stepping motor to accurately position a load without using a feedback system, such as a resolver or compatible encoder. Feedback systems may be incorporated into the stepping motor system to provide a comparative function or to provide a true closed-loop system, although as a rule, stepper motors are run open-loop. A position sensor may be required to determine a "home" position if control power is interrupted. Stepper motors become thermally hot regardless of whether they are turning or not. Also, when power is lost, the motor can no longer support a load. When installing the stepper motor in a hot cell, it may be necessary to separate the electronic drives from the motor and move them out of the cell or to a lower radiation area. Note that motor performance may be affected when separating the electronics and the motor. Consideration should be given to reduce the generation or reception of electrical noise on the cables between the drive and the motor.

8.2.7 *Induction Motors*:

8.2.7.1 Induction motors come in either three phase or single phase. At lower horsepower ratings, the single-phase motor is more commonly used by equipment vendors. The single-phase induction motor requires an internal wiring method to develop starting torque such as a starting winding and capacitor. Three phase induction motors (squirrel cage) are simple, dependable and work well in hot cells. In an induction motor, the AC voltage is supplied directly to the stationary stator winding and this generates a rotating magnetic field in the stator winding. The rotating magnetic field of the stator induces a current in the rotor of the motor. The current flowing in the rotor generates a magnetic field that causes the rotor to rotate. Variable frequency drives are commonly used to control motor speed when using a three phase induction motor.

8.2.8 *Linear Motors*:

8.2.8.1 Linear motors are typically used to move objects along a horizontal track. The linear motor and track can be straight or may contain slight curves. In hot cell applications, their primary use would be to move material in carts. Linear motors produce linear motion with only a stationary component, usually the stator, and a moving component, usually a reaction plate or a permanent magnet, located on the cart. The simplicity of a linear motor gives it an advantage over conventional motors and cylinders used to produce a linear motion because the linear motors do not require additional hardware to convert rotary motion to linear motion. Also, linear motors typically can control acceleration, speed and multiple (more than two) positions more precisely than a pneumatic or hydraulic cylinder. There are two types of linear motors; linear induction motors and linear synchronous motors.

8.2.8.2 *Linear Induction Motor*:

(1) A linear induction motor is essentially a three-phase, rotary, induction motor with the squirrel cage, or stator, laid flat. When energized, a three-phase, AC, traveling-wave magnetic field is produced in the stator. The reaction plate is the equivalent of the rotor. Currents are induced in the reaction plate by the traveling wave. The reaction between these two fields produces linear thrust. The primary induces a magnetic field in the secondary that is opposite the field produced in the excited primary. This produces the motive force. When stopped, no induced field is produced in the secondary, and therefore no holding force is available without using ancillary braking systems. Also, since it is an inductive process, heat is produced in the secondary that must be dissipated. Duty cycle, secondary surface area, position sensors, and convection cooling requirements must be considered when selecting a linear induction motor.

8.2.8.3 *Linear Synchronous Motor*:

(1) A linear synchronous motor is similar to a linear induction motor; however, the reaction plate is replaced by a permanent magnet, so that the magnetic field is permanent, not induced. Typically, there is no significant heating of the magnet of a linear synchronous motor. A linear synchronous motor may hold the load in a fixed position with no significant heating of the magnet, which can be a significant advantage in hot cell applications.

8.2.9 *Motor Enclosure Types*:

8.2.9.1 *Open Drip Proof (ODP)*:

(1) These motors have venting in the end frame situated to prevent drops of liquid from falling into the motor within a 15 degree angle from vertical. These motors are designed for use in areas that are reasonably dry, clean, and well ventilated.

8.2.9.2 *Totally Enclosed Non-Ventilated (TENV)*:

(1) These motors have no vent openings. They are tightly enclosed to prevent the free exchange of air, but are not airtight. TENV motors rely on convection for cooling. They are suitable for use in areas where the atmosphere is damp or dirty. TENV motors are preferred over ODP motors for hot cell use because of the reduced potential for internal contamination. If used in an atmosphere other than air, the motor should be de-rated. For example, in argon gas atmospheres, the motor should be de-rated by at least 70 % because convection heat removal in argon gas is less than in air.

8.2.9.3 *Totally Enclosed Fan Cooled (TEFC)*:

(1) These motors are the same as TENV except that they have an external fan that provides cooling air over the outside of the motor frame.

8.2.9.4 *Explosion Proof*:

(1) These motors are specifically designed for use in hazardous (explosive) locations. Explosion proof motors can be TENV or TEFC.

8.2.10 *Motor Mounting*:

8.2.10.1 Commercially available or off-the-shelf motors used in a hot cell should be of a standard NEMA frame size. Standard NEMA motor frames come in a variety of sizes and often have a letter suffix which provides more specific frame information. If necessary, the frame mounting can be modified as required to accommodate different mounting schemes. Note that stepper and servomotors may not be available in NEMA motor frame sizes. **NEMA MG1**

8.2.10.2 The standard motor frames should be mounted to brackets or to remotely removable mountings. These mountings may in turn be held in place using toggle clamps and aligned using dowel pins or tapered guide pins. Other fastening systems include ball-lock pins or captured bolts. Occasionally, it is advantageous to make the motor and its mount sufficiently heavy to keep them in place by gravity and eliminate the need for fasteners.

8.2.11 *Causes of Electric Motor Failure in a Hot Cell*:

8.2.11.1 Motor failure in a hot cell is generally from the motor brushes or the electrical connecting cables. Motor windings are rarely the cause of motor failure in a hot cell.

8.2.11.2 A common reason for motor failure in a hot cell is that over time, the constant exposure to radiation embrittles the wire insulation, and the constant flexing of the wire cables causes the brittle insulation to crack and the wires to short circuit. A silicone rubber coated glass fiber-reinforced sleeving over the wire insulation has sometimes been used to minimize the effects of insulation failure.

8.2.11.3 In argon gas atmosphere hot cells, over-heating is a cause of motor failure because of the poor heat transfer characteristics of argon gas. Additional failures may result from higher electrical conductivity or low breakdown voltage of argon gas. Experience has shown that in an argon atmosphere hot cell, moisture content less than 50 ppm water causes motor brush failure. The lubrication properties of the motor brush depend on the graphite content of the brush and on the layer of copper oxide (commutator surface) that normally forms in the presence of oxygen and moisture. In argon atmosphere hot cells with low moisture, the standard motor brushes have been replaced with high altitude brushes made of silver-loaded self-lubricating carbon to extend the life of the motor.

8.2.12 *Pneumatic Motors*:

8.2.12.1 Pneumatic motors are generally less expensive and smaller than electrical motors, but they are not typically used in hot cells for several reasons. First, the high volume and velocity of the gas required to operate the tool contributes to the spread of radioactive contamination inside the hot cell; second, the introduction of an increased volume of gas into the hot cell may cause problems with the hot cell pressure control system; and third, they generally require frequent lubrication. Pneumatic motors and tools may be useful in applications where the motor may experience frequent stalls. The type of gas used to power the motor/tool must be compatible with the hot cell atmosphere. The type of application and the consequences of using a pneumatic motor/tool in a hot cell should be thoroughly evaluated before placing the motor into service.

8.2.13 *Hydraulic Motors*:

8.2.13.1 Hydraulic motors are not typically used in hot cells because it is generally undesirable to introduce a moderator (hydraulic fluid) into the hot cell and because there is a potential for a hydraulic fluid leak. In cases where hydraulic motors are used in hot cells, the reservoir and pumping system components are located outside the cell and the hydraulic hoses pass through the cell wall boundary through a feed-through. Another potential problem would be the cleanup and disposal of radioactively contaminated hydraulic fluid in the event of a leak inside the hot cell. When hydraulic systems are used, consideration should be given to using fluids that are non-hazardous (RCRA) and do not present flammability or mixed waste disposal problems if they become radioactively contaminated.

8.2.13.2 The hydraulic hose should be made of a material suitable for hot cell environments and be rated for the expected hydraulic pressure.

8.2.14 *Motor Maintenance/Repair/Replacement*:

8.2.14.1 Maintenance, troubleshooting, and repair of motors should be performed by personnel familiar with the equipment.

8.2.14.2 Repair of motors that have been used in a hot cell can be difficult and time consuming. It is generally advisable to discard and replace motors that fail in service. The motors should be equipped with a mounting scheme that allows easy change-out of the failed motor using the remote handling methods. Otherwise, the equipment may have to be transferred to a radioactive repair area where personnel suited in protective clothing enter to repair and/or replace the failed motor. **C 1554**

8.2.14.3 Motors should be periodically checked for loose connections. Also, the heat sink areas should be cleaned regularly and the vent slots should be cleared of dust and debris on motors that require forced cooling.

8.3 *Bearings/Bushings*:

8.3.1 *General*:

8.3.1.1 Bearings and bushings are often designed as part of a larger subassembly that will be replaced if needed due to the problems of replacing individual pieces installed with typical clearances. If desired, commercial split-housing bearings can be mounted with more complex tapered shafts as shown in Figs. 1 and 2 for individual remote disassembly and replacement. Any advantages gained with this approach must offset

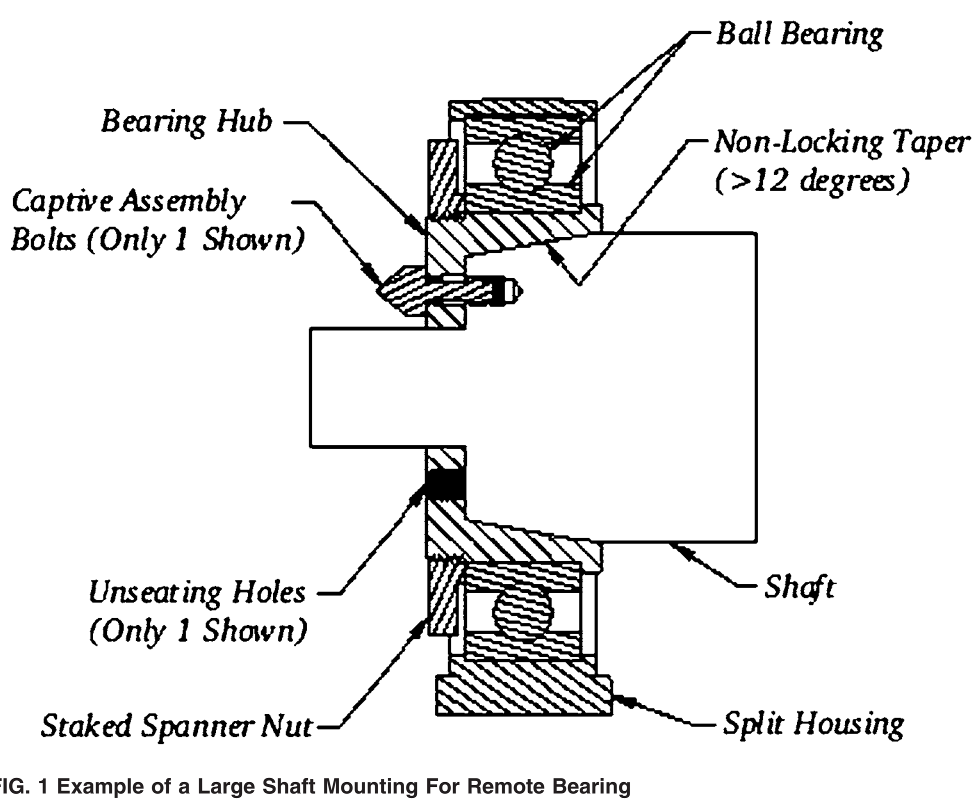

FIG. 1 Example of a Large Shaft Mounting For Remote Bearing Replacement

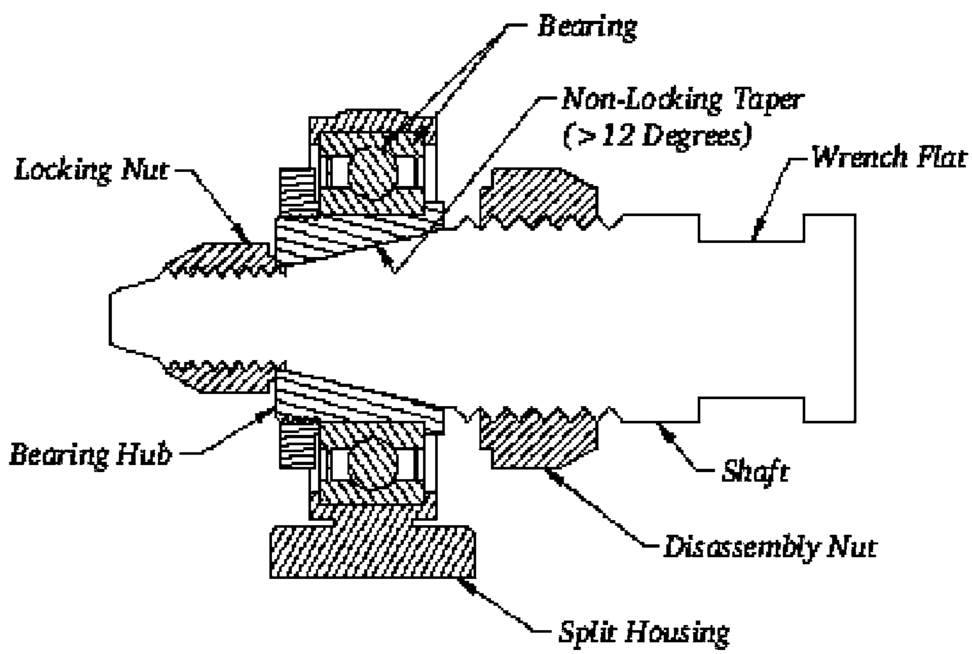

FIG. 2 Example of a Small Shaft Mounting for Remote Bearing Replacement

the increased initial costs. It is recommended that a proper lubricant be selected and that bearings used in-cell be lubricated for the life of the bearing. Only bearings and bushings designed to be operated and replaced in a remote hot cell environment should be considered for use in this type of facility, unless the module containing the bearing is designed to be replaced in its entirety. Bearings should be a self-contained unit to avoid loss of parts during maintenance. Typically, bearings used in hot cells can be classified as 1) ball, 2) roller, 3) needle, 4) tapered roller, and 5) thrust types. The bearing vendor should be consulted in determining the type of bearing to utilize for the service intended.

8.3.1.2 An alternative to the standard lubricated bearing is one that has been modified for hot cell use. This bearing modification involves replacing the inner-cage with high altitude graphite blocks, see Fig. 3. The graphite blocks provide a dry lubrication without a medium to trap radioactive contamination and also provide the spacing for the balls around the bearing races. These modified bearings have been used successfully in hot cells at low to moderate speeds at high temperatures in a highly radioactive and contaminated argon atmosphere hot cell where conventional sealed and lubricated for life bearings were unable to provide satisfactory service.

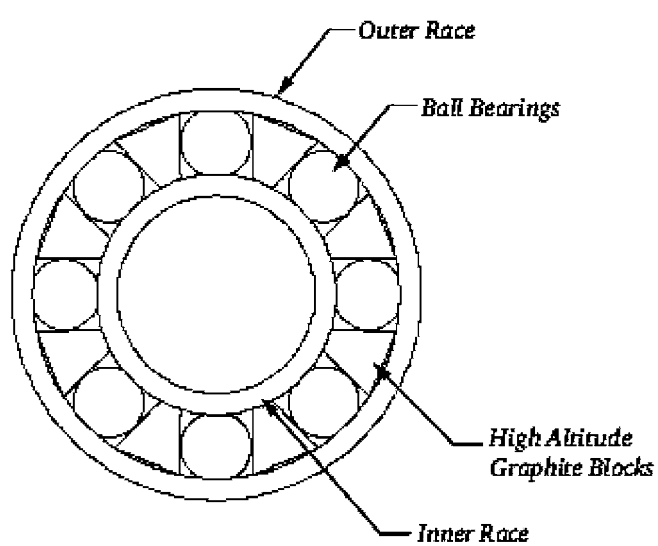

FIG. 3 Cross Section of a Bearing Modified with Graphite Blocks

8.3.1.3 Pneumatic (air) bearings are typically not suitable for radioactively contaminated hot cell environments. Introduction of large volumes of air into a hot cell in air bearing applications may be detrimental to the cell ventilation parameters and may contribute to the spread of radioactive contamination throughout the hot cell. A pneumatic bearing uses a film of air supplied from a compressed air source between the two surfaces. The compressed air is at a higher pressure than the surrounding environment and if allowed to work over a large surface, can provide ease of movement for large and heavy objects. Pneumatic bearings require that the two surfaces be flat and smooth and the object being moved must have sufficient underneath surface area to provide the lifting capacity. They have also been used in rotating devices that rotate at high revolutions per minute, but these units tend to be very small. Pneumatic bearings may be considered for limited applications such as in cases where zero friction is critical. They require additional hardware such as pumps, filters, valves and piping to operate and they require high gas velocities and pressures which increase the potential for dispersal of contamination.

8.3.1.4 Bushings generally fall into two categories, impregnated and non-impregnated. Impregnated bushings generally are of a sintered powder metal with a porous substrate. A suitable grease or oil has been forced into the interstitial spaces of the substrate to provide a reservoir for the lubricating material. This approach can provide sufficient lubrication for a finite period of time depending on the application. However, replenishment of the lubricating material should be provided in the form of an oil or grease reservoir outside of the bushing area. Non-impregnated bushings must be supplied with oil or grease from an external reservoir. Some bushings may have a surface treatment such as a silver deposit, hard chromium, molybdenum disulfide, or a graphite deposit, that reduces or eliminates the need for external lubrication.

8.3.1.5 Non-metallic bearings are generally made from plastic type materials which in general offer poorer radiation resistance than metallic counter-parts. These bearings generally are of the sleeve type and rely on the slick or slippery nature of the material surface properties for lubrication. In this type of configuration (sleeve type), the plastic bearing is generally designed to accommodate light to moderate radial loading (depending on contact loads and frictional temperatures). The plastic type bearings typically do not require additional lubrication from grease or oil materials and are generally employed in items that are of a disposable nature. Without having a lubrication medium such as grease or oil to provide the lubrication properties, the plastic material can fail due to excessive heat build-up, which destroys the specific purposes for which the bearing was used. This problem is aggravated by the general nature of radiation degradation of plastic materials. Plastic bearings can offer better corrosion resistance than metallic counter-parts, depending on the environment. Plastic materials such as the polyetheretherketones, have shown to be good candidates for bearing surfaces where low speeds are involved such as in valve stem seals and seats in ball valves. Plastic bearings should only be used after giving careful consideration to the particular application.

8.4 *Torque Transfer Components*:

8.4.1 *General*:

8.4.1.1 Most gears used in hot cell applications are metallic. Non-metallic gears should be evaluated for their resistance to radiation damage prior to use in a hot cell. The use of non-metallic gears, typically manufactured from plastic type materials, has many of the same limitations as mentioned regarding plastic bearings. Typically, components using plastic gears that would be selected for use in a hot cell environment would be of a disposable nature requiring routine replacement. Gears limited to light duty load ratings with a limited life-span use in a hot cell environment may be justifiable from a cost stand point if a cost trade-off can show that this an economical approach to a given design situation. Plastic gears, by the very nature of the non-metallic material, can be more quiet running than metallic gears, which may be of some importance in general design applications, but typically is not selected for use in a hot cell environment. Typical applications in a hot cell environment for plastic gears would include small fractional horsepower motors with geared shafts on laboratory type equipment that has a finite life span and is easily replaceable.

8.4.2 *Gears*:

8.4.2.1 Gears are typically produced in commercially available types and sizes and are manufactured to the American Standard and American Gear Manufacturers Association standards. Proper gear alignment is crucial for the life cycle and performance of gearing systems. Often, a motor having a gear mounted on the shaft will have precision alignment holes in the mounting bracket that mate with dowel pins on the parent part. Consideration should be given to using the lowest diametrical pitch possible to minimize the need for precision fit between mating gears. Mating gears should be mounted on the same module to provide alignment without requiring in-cell adjustment. **AGMA 390.03**

8.4.2.2 Radiation resistance lubricants should be used. Refer to Fig. 4.

8.4.2.3 Safety factors of 3:1 or greater based on the yield strength of the material should be used when designing gearing systems. Larger safety factors should be used if shock or vibration is present.

8.4.2.4 Pressure relief provisions should be included in the design of enclosed gear housing to prevent lubricant leakage or damage to seals when the housing is transferred across cell boundaries through transfer locks having high pressure differentials.

8.4.2.5 Consider the specific application in order to choose the appropriate gear type, i.e., the self-locking capability from a worm gear, a high torque in a compact design from a planetary gear, or linear motion provided by a rack and pinion gear.

8.4.3 *Composite Belts*:

8.4.3.1 Composite belts are not generally used in hot cells except in temporary applications. The belt material is typically sensitive to radiation damage and embrittles, cracks, and breaks over time.

8.4.4 *Chains and Sprockets*:

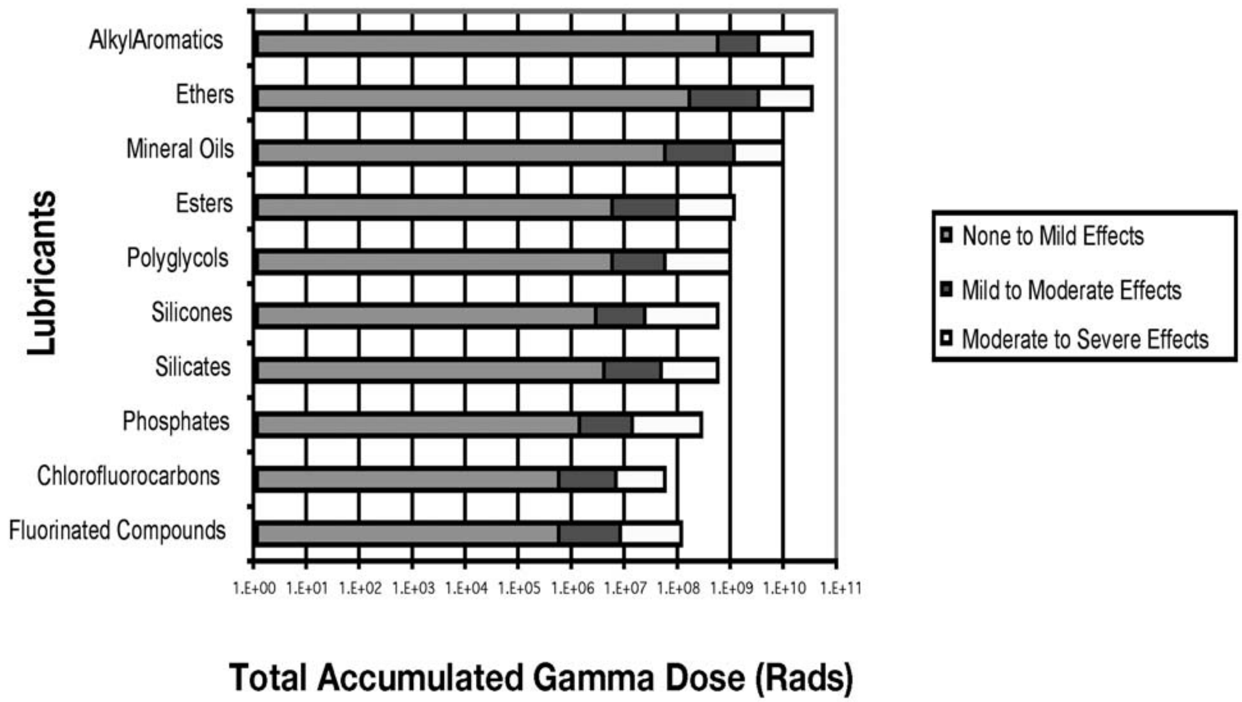

FIG. 4 Radiation Resistance of Lubricants (CERN 70-5)

8.4.4.1 Chains and sprockets are typically not used in hot cells because of the difficulty in lubrication and in replacing a broken chain remotely.

8.4.5 *Rigid Shafts*:

8.4.5.1 Rigid shafts may be round, square, or hexagonal shaped. A typical round shaft requires a shaft key or set screw to provide the power transmission. Shaft keys are used to transmit the torsional force from the shaft into another rotating component. The keys are typically produced in standard commercially available sizes and the key ways are cut to standard dimensions. Since shaft keys are difficult to replace in a hot cell using the master-slave manipulators, the components are usually transferred into a contaminated repair area where suited personnel perform the repairs and replacements. The shaft key should be held in place using a set screw through the mating part and the screw should be held in place using a thread locking compound. Square or hexagonal shafts have the advantage of being easy to assemble remotely since there is no key and key slot. Shaft material selection is important to avoid galling. Excessive shaft length should be avoided to prevent shaft wobble or whirring. **ASME B17.1**

8.4.6 *Flexible Shafts*:

8.4.6.1 Flexible shafts transmit rotary motion in a curved path and are made of high tensile strength metal cables encased in a flexible protective casing. They are used in applications to replace complex assemblies of linkages, gears, and other power transmission devices. They also have the advantage of absorbing vibration, and can withstand load changes caused by sudden starting and stopping. In hot cell use, they can be used inside a feed-through to allow an out-of-cell motor to provide rotary motion to an in-cell component. Another advantage is in the case where it may be difficult to put the motor in close proximity to the rotating part. A disadvantage is that flexible drive systems often require frequent re-lubrication for good reliability and long life which may be difficult to achieve in a remote environment. Consideration should be given on how to modularize a flexible drive shaft mechanism and how to remotely replace it. Care should be taken to not exceed the manufacturers recommended maximum bend radius or load. Commercial flexible drives typically use threaded collars for installation that are difficult to manipulate with remote equipment. Typically, flexible drives should be a part of a larger sub-assembly module for ease of replacement and maintenance.

8.4.7 *Torque Limiters and Slip Clutches*:

8.4.7.1 Torque limiters and slip clutches provide a safety mechanism to prevent damage to the motor or to other components. The torque limiters and slip clutches are composed of spring loaded metal plates that sandwich a fibrous material having a high coefficient of friction. When the torque demand exceeds the preset torque value, the metal plates begin to slip on the fibrous material and reengage when the torque is reduced. These devices provide an effective, non-electrical means for limiting the rotational force applied to components and have been used successfully in hot cells because of their simplicity and resistance to radiation damage.

8.4.8 *Brakes*:

8.4.8.1 Brakes provide immediate braking for applications requiring rapid stopping and holding power. Some brakes engage and hold the load when power is off and automatically release when power is re-applied. Other types of brakes combine a clutch with a brake and stop and start the load when power is switched between and clutch and the brake.

8.4.8.2 Design of braking mechanisms should incorporate fail-safe features for safety and to protect equipment and any operating process. This is generally accomplished by requiring the brake to be engaged or activated when electrical power is off. If a loss of power occurs, the brake activates and stops the motion.

8.4.8.3 Since brakes have similar properties to motors, they can operate in a hot cell for extended periods of time. However, in inert gas atmospheres such as argon, the poor heat transfer characteristics will cause the brake to run hotter which may result in reduced capacity.

8.4.9 *Couplings/Splines*:

8.4.9.1 Couplings are used extensively in hot cells to connect motor shafts to drive shafts and allow the motor to be easily disconnected and replaced in the event of a failure. Couplings also provide for some degree of misalignment, reducing the cost for precision alignment features. Couplings used in hot cells are typically made of metal. Couplings should be selected based on their degree to accommodate misalignment, their ability to accommodate shock loads, and the required rotational speed requirements.

8.4.9.2 Splines are similar to couplings except that the spline shaft is made with concave races along the length of the shaft. The spline has matching features that engage the races in the shaft. The spline is typically mounted onto the motor shaft and the spline shaft is usually cut short and fastened to the drive shaft. The mating ends of the spline and spline shaft are chamfered to provide some lead-in during engagement of the parts for remote applications. Prominent alignment marks on the splines and couplings can aid the operator during assembly of the parts.

8.5 *Lubricants*:

8.5.1 *General*:

8.5.1.1 Lubricants are used between sliding and rotating surfaces to reduce friction, reduce wear, remove heat, shield against external contamination, and prevent corrosion. The environment in a typical hot cell can be damaging to lubricants and bearings. Besides the typical speed and loading issues, there are design and operating issues relating to radiation exposure, inert atmosphere, high temperatures, corrosive chemicals, and airborne contamination. Failure to appreciate these challenges both individually and collectively can result in early bearing failure. In-cell application of lubricants is generally not recommended due to the difficulty of application techniques and concerns of introducing a neutron moderator into the hot cell, contamination control, and waste disposal of unused lubricant. Instead, components requiring lubrication are typically lubricated prior to admitting the component into the hot cell. In some cases, slow speed lightly loaded bearings may provide adequate design life with no lubrication. Lubricants are generally produced in the following forms: liquid, semi-solids, solid, and dry.

8.5.1.2 An inert atmosphere with low humidity levels increases the rate that volatile components leave the lubricant, affecting its lubrication qualities. High temperature processes accelerate the volatility problem and can add a clearance problem if there is a high temperature gradient between the inner and outer bearing races. Lubricants vary considerably in the amount and composition of the residue that is left behind. In severe instances, the lubricant residue begins to function as an abrasive compound and destroys the components it was meant to protect. Limited testing has shown that a perfluoroalkylpolyether lubricant leaves no visible residue, has good high temperature capability, and good radiation resistance.

8.5.1.3 A hot cell atmosphere is often very turbulent as a result of ventilation systems maintaining correct temperature and pressure. Contamination is spread quickly and easily resulting in a highly contaminated environment. Lubrication can trap airborne contamination which in turn may promote destruction of bearings and bearing surfaces long before design life expectancy is reached. Liquid and semi-solid lubricants have a greater susceptibility to this problem and as a result, coatings and dry or solid lubricants are often specified as desired alternatives when the design permits.

8.5.1.4 The presence of corrosive chemicals in a hot cell may adversely affect the effectiveness of lubricants. The compatibility of a lubricant used in the presence of corrosive chemicals should be evaluated prior to use.

8.5.1.5 Radiation generally affects all lubricants by both breaking molecular bonds and cross-linking new molecular bonds. Breaking bonds releases hydrogen and other gases. Liquid lubricants will generally endure more radiation than semi-solid lubricants. Greases may initially become softer due to scission of the thickener, but eventually they harden, as cross-linking of the molecules become the dominating effect. Specific effects are dependent on the composition of a given lubricant. For example, diester synthetic base oils, phosphate esters (anti-wear additives), and halogenated materials (extreme pressure agents) each produce acids when exposed to low radiation doses. Common polymers such as polybutenes and polymethacrylates cleave readily and thus lose their viscosity-index improving function. Silicone antifoam agents are also easily destroyed. High aromatic content promotes radiation resistance. This is all in addition to the normal effects of an oxidizing atmosphere and increasing temperature that lower the useful life of lubricants. In general, experience has shown that lubricants made from alkylaromatic-type base oils with special additives provide the best radiation resistance.

8.5.1.6 When specifying a lubricant for hot cell use, it is advantageous to have the vendor assemble the bearing with the lubricant of choice at the time of manufacture. Otherwise, the bearings must be disassembled, cleaned, and re-lubricated at the user's facility prior to use. The cleaning procedure is complicated if seals or shields must be removed and reinstalled without damage. Light transformer oils, spindle oils, or automotive flushing oils are suitable for cleaning bearings, but oils heavier than SAE 10 motor oil are not recommended. The use of compressed air should be allowed only after filtering out any possible dirt and moisture. Chlorinated solvents are not recommended because of possible corrosion due to residual chlorine left on bearing surfaces. Care should be taken to not over-lubricate a bearing as this may cause excessive heat generation and shortened bearing life. Bearing housings should be typically filled between ⅓ and ½ of the void space with lubricant.

8.5.1.7 Since many lubricants are flammable, consideration should be given to the combustible loading in the hot cell. A review of the heat sources in the vicinity of the lubricants and their effects on the lubricants may be necessary.

8.5.1.8 Most lubricants are considered neutron moderators because of their content of organic materials. Control of lubrication material quantity and location is often a factor in not allowing re-lubrication of components. A criticality evaluation should be conducted in applications where the lubricants are in close proximity to the nuclear materials.

8.5.1.9 Consideration should be given to potential radioactive contamination of lubricants and their method of disposal prior to their use in a hot cell. Because of their constituents, some lubricants may have to be disposed of as mixed waste.

8.5.1.10 Liquid lubricants are either petroleum based (refined mineral oil or synthetic oils synthesized from petroleum stocks) or synthetic fluids synthesized from non-petroleum based chemicals. The petroleum-based lubricating liquids are not compatible with the non-petroleum-based fluids. Mixing of the two different base liquids can result in a two-component fluid phase that will not provide a continuous lubricating film. Figure 1 lists the radiation resistance of some lubricants. In general, ASME NOG-1, Section NOG-5460, recommends the use of NLGI Grade 0 oil containing molybdenum disulfate or NLGI Grade 1.5 grease with sodium aluminate thickener. The lubricants should be oxidation and rust inhibited. **ASME NOG-1**

8.5.1.11 Non-petroleum-based synthetic lubricants were developed in part for specific performance levels not achievable with petroleum-based lubricants. It should be noted that some physical properties may have been enhanced at the expense of other properties. For example, many very high-temperature lubricants have very short service lifetimes when compared to normal lubricants. Common synthetic lubricants include polyglycols (glycols, polyethers, polyalkylene glycols), phosphate esters, dibasic acid esters, silicones (organosilioxanes), and fluorinated polyethers. **NLGI**

8.5.1.12 Semi-solid lubricants, or greases, are also either petroleum based or synthetic material synthesized from non-petroleum based chemicals. Semisolid lubricants suspend a liquid lubricant in a semi-fluid mixture having additives to obtain the desired consistency, viscosity, rust prevention capability, antioxidants, viscosity-index improvement (change in viscosity with change in temperature), and extreme pressure capability. Extreme pressure additives are sacrificial solids added to prevent a metal-to-metal contact if the lubricating fluid film fails. Mixing greases of different viscosities should be avoided as it can result in grease that is too viscous or not viscous enough to lubricate properly. Depending on the intended service, consideration should be given to using greases and oils suitable for high radiation fields that are typically encountered in a hot cell environment. NLGI grade 2 grease has been found to be suitable for applications in high radiation areas. **NLGI**

8.5.1.13 An alternative to the liquid and semi-solid lubricants is the use of solid lubricants. Solid lubricants are sponge-like materials that store and release a lubricating liquid from its matrix. Examples of solid lubricants are phosphor-bronze and graphite. A successful use of a solid lubricant involved replacing the standard bearing cage in a commercial deep groove ball bearing with high altitude graphite blocks. The graphite provided a continuous film of lubrication to the rotating balls and did not readily trap contamination. This bearing configuration is shown in Fig. 3.

8.5.1.14 *Dry lubricants*:

(1) Dry lubricants are typically finely ground powders with very low shear strengths and lamellar structure. Placed between two opposing surfaces, the lamellas orient parallel to the surfaces in the direction of motion to prevent contact of the two surfaces. Examples are graphite, molybdenum disulfide, boron nitride, PTFE, talc, calcium fluoride, cerium fluoride, and tungsten disulfide. Review of the individual characteristics of each lubricant will help determine the specific applicability for use.

(2) Considerations for using dry lubricants in hot cells include: 1) presence of a slight amount of water vapor for graphite to function effectively as a lubrication, 2) the radiation resistance of inorganic dry lubricant compounds is typically better than the radiation resistance of organic formulations, 3) the chemical reactivity and operating temperature may affect operation, 4) use of the lubricants as a free powder is not recommended due to poor adhesion and service life, 5) dry lubricant applied as a thin coating and bonded to the surface has proven successful in solving many lubrication problems including high temperatures and reactive chemicals, and 6) a self-lubricating bearing with machined grooves or holes filled with a dry lubricant such as graphite.

8.6 *Linear Positioning Systems*

8.6.1 *General*:

8.6.1.1 Positioning systems are frequently required in hot cell facilities due to the high radiation and/or contamination fields that pose serious health and safety concerns to personnel. In this context, the positioning systems must be able to reliably and cost effectively perform the intended function until required maintenance or replacement can be effectively done on the component. Positioning systems should be easily operable and their function should be understood by all personnel intending to use this equipment. Key parameters that control function and direction of movement should be easily discernable by operations personnel so as to prevent or at least limit movements that may be detrimental to hot cell equipment or operations. Failure of positioning systems is obviously dependent on the type of positioning system. They should be designed for easy replacement in a hot cell environment. This means that access to the positioning device by remote methods needs to be provided unless the entire component or subassembly can be removed from the hot cell for servicing, repair, and or replacement. To the greatest extent possible, the type, size, connection interface(s), and power supplied to positioning devices should be the same. This approach affords ease of repair and or replacement, minimizes the number of spares (or spare parts kept in inventory), while enhancing overall reliability of systems operation in the hot cell facility.

8.6.1.2 *Leadscrews*:

(1) A leadscrew is a long threaded rod which is generally fixed at one or both ends in threaded guides mounted to a frame and are used for linear positioning of equipment. In the case where the leadscrew is fixed on both ends, the leadscrew rotates and moves a nut to the desired position. In the case where one end is fixed, the drive nut rotates, which forces the

leadscrew to move in either direction producing linear travel. In hot cell applications, leadscrews are typically driven using electric motors that are connected directly to the leadscrew, either directly or through a geared drive system. Leadscrew positioning systems can achieve high accuracy positioning when fabrication is held to tight tolerances.

8.6.1.3 *Screw Jacks*:

(1) The jack screw provides a method to move a component in relation to another component, which is usually the reference interface. The jack screw is typically a relatively short threaded rod which is threaded through one component and is allowed to rest and push on another component. The intent of a jack screw is to push one component away from the opposing component interface usually as a means of leveling or separating surfaces. Jackscrews are typically not motorized, since the intended movement between components is relatively small, as in the case for making leveling adjustments. In a hot cell environment, operation of jack screws may require the use of some type of manipulator arm and auxiliary tooling to perform the rotational movement of the jack screw.

8.6.1.4 *Pneumatic*:

(1) Air cylinders, typically called pneumatic cylinders, can be used as positioning devices. Due to the inherent operating nature of a pneumatic cylinder, positioning of a component on the end of a piston rod is either at full retraction or full extension of the unit, nothing in between. This type of articulation in a hot cell environment is typically used for opening/closing a quarter-turn (ball) valve, opening/closing a ventilation damper, or positioning an object from position 1 to position 2.

8.6.1.5 *Hydraulic*:

(1) Hydraulic positioning systems are typically not used in hot cells due to the difficulty in maintaining the system leak free, the short life expectancy and high disposal costs of fluids, and the concerns of introducing a moderator into the hot cell. Overcoming these problems is time consuming and expensive, giving the edge to the use of mechanical systems. Positioning by hydraulic methods either by linear rams (cylinders) or rotary mechanisms can provide very high forces to position heavy objects within a hot cell environment. However, for the aforementioned reason about the use of hydraulic fluids, positioning systems using other methods such as lead screws or pneumatic cylinders are usually the preferred method. Due to the concerns about hydraulic fluids in the hot cell environment, several manufacturers have formulated water-based hydraulic fluids in lieu of organically based liquids to overcome some of the concerns with typical hydraulic fluids.

8.6.1.6 *Electrical*:

(1) Electric actuators for positioning components can be either full extension or full retraction, such as a solenoid or have the capability to position anywhere in between the two extremes such as a linear actuator. Electric positioning devices are probably the most common device used in the hot cell for this purpose. These units are easy to control and can be programmed with the appropriate controller/software to perform a variety of positioning functions with very precise tolerances.

8.7 *Position Indicators*

8.7.1 *General*:

8.7.1.1 Position indicators are used in conjunction with positioning systems and provide feedback to the operator of the relative or absolute position of components. Position indicators are essential in hot cell applications where accuracy and repeatability of operations are important, and for troubleshooting. Often it is necessary to provide redundant position indicators, so that in the event that one of the positioning systems fails, there is still one source of position indication.

8.7.2 *Resolvers*:

8.7.2.1 Resolvers are rotational position measuring devices that resemble small rotors. They are essentially rotary transformers with secondary windings on the rotor and stator at right angles to the other windings. When a rotor winding is excited with an AC reference signal, the stator windings produce AC voltage outputs that vary in amplitude according to the sine and cosine of shaft position. The stator signals are routed to an analog–to-digital converter system. Connection to the rotor is made by the brushes and slip rings, or inductive coupling. Resolvers using the inductive method are referred to as brushless resolvers. The brushless resolvers usually last much longer than brush-type resolvers and are less sensitive to vibration and dirt. Resolvers are the preferred feedback device for hot cell use since they do not require any semi-conductor electronics to be in the hot cell in order to operate.

8.7.3 *Encoders*:

8.7.3.1 Encoders are measuring devices that detect changes in rotary or linear motion, direction of movement, and relative position. Encoders produce electrical signals from mechanical components in motion that are read through the use of a converting device. Incremental encoders indicate how far a shaft has rotated or moved. Absolute encoders indicate the actual angular position of a shaft. The most prevalent encoders work through optics. Typical rotary optical encoders transmit light through a printed code disk and onto sensors, where electrical pulses are generated and counted to determine shaft position. Optical encoders are generally not recommended for hot cell use because the optical disk in the encoder turns brown from prolonged radiation exposure preventing light from passing through the glass disk. Magnetic encoders are preferable to optical encoders, but are not as common and may be physically larger in size.

8.7.4 *Linear Variable Differential Transformers (LVDT)*:

8.7.4.1 LVDTs measure linear displacement and can also be used to measure pressure, weight, and liquid level. The principal features of a LVDT are its good linearity, accuracy, and high sensitivity over a large range. LVDTs are also robust because there is no physical contact across the sensing element which eliminates any potential wear. LVDTs can also be made to be waterproof which is useful to prevent internal contamination from radioactive materials in a hot cell environment.

8.7.5 *Switches*:

8.7.5.1 *General*:

(1) Switches provide a reliable and accurate indication of position. Switches used in a hot cell should be mounted so that they can be easily replaced. The switch mounting scheme must take into account any positional adjustment to avoid differences in trip points when a switch is replaced.

8.7.5.2 *Proximity*:

(1) Proximity sensors are typically either inductive or capacitive. Inductive sensors produce a magnetic field and are used to sense metal objects only, whereas capacitive sensors are primarily used to sense nonmetallic objects. Both sensors operate by detecting the presence or absence of a target object and send a signal to a readout instrument. Proximity sensors are usually effective in a range less than 20 mm (0.75 inches). Capacitive models have electronic circuitry contained in the sensor that may be subject to radiation damage and are not suitable for high radiation environments. Inductive sensors that do not have internal electronics are typically resistant to radiation damage. An advantage of proximity sensors is the lack of moving parts.

8.7.5.3 *Photoelectric/Light-Sensing*:

(1) Light sensing indicators typically have a transmitter and a receiver unit. Light sensing indicators are generally not used in hot cells because they are susceptible to radiation damage. The glass in the sensors becomes discolored from prolonged radiation exposure and eventually fails to send or receive the signal and the semi-conductors may also fail to operate.

9. Hazards

9.1 *General*:

9.1.1 There are hazards associated with operating mechanical drive systems in a hot cell and operators should be trained to recognize those hazards. Some hazards include the potential for electrocution if the slave end of the master-slave manipulator touches a power source or frayed cables. The master-slave manipulators should always be locked and tagged-out during repair of in-cell electrical systems when there is a potential for accidental electrocution. Another hazard is that mechanical drive systems are typically not guarded, so care must be taken when handing equipment around operating machinery to avoid contact with the moving parts. For example, if the slave end of a master-slave manipulator were to accidentally get caught by a moving part, there may be sufficient force to injure the operator on the master end of the manipulator. In cases where personnel may enter the hot cell, consideration should be given to providing guards for rotating equipment. The high rotating speed and torque of some machines may present a hazard to the hot cell boundary in the event that a part fails. A projectile from a broken part may be ejected with sufficient force to break a hot cell radiation shielding window or through-wall viewing system. In such cases, consideration should be given to guarding the machinery to protect against such failures. Another potential hazard comes from toxic fumes given off from some plastic materials, such as PTFE, when the material is exposed to radiation. Personnel should always wear the proper protective clothing and breathing protection when entering radioactive repair areas or hot cells. **C 1572**

10. Special Requirements

10.1 Purchased mechanical drive system equipment should be inspected upon receipt at the owner-operator's site per requirements specified by the owner-operator. These inspections may include dimensional inspections, functional testing to verify operability, and verification of the vendor's certificates of conformance or other documentation. The required documentation shall be specified according to the requirements of the owner-operator per the quality assurance requirements pertaining to documentation specified in Section 5.

10.2 Where appropriate, purchased equipment should include an operator's manual.

10.3 Equipment should be appropriately packaged and shipped to prevent damage to the components while in transit.

10.4 The owner-operator should consider all seismic implications associated with installation and operation of mechanical drive system components in a hot cell. Considerations should include mounting schemes, attachment methods, and the potential for breaching the confinement boundary if a seismic event occurs. The owner-operator should review and consider specific seismic requirements and building codes in the design of mechanical drive systems.

10.5 Where suitable information is available, the design life and radiological duty cycle of mechanical drive system components should be specified by the owner-operator for purchased equipment.

11. Keywords

11.1 mechanical drive systems; remote handling; motors; gears; bearings, lubricants.