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Standard Guide for Mechanical Drive Systems for Remote Operation in Hot Cell Facilities¹

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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

[C859 Terminology Relating to Nuclear Materials](#)

[C1533 Guide for General Design Considerations for Hot Cell Equipment](#)

[C1554 Guide for Materials Handling Equipment for Hot Cells](#)

[C1572 Guide for Dry Lead Glass and Oil-Filled Lead Glass Radiation Shielding Window Components for Remotely Operated Facilities](#)

[E170 Terminology Relating to Radiation Measurements and Dosimetry](#)

2.3 Other Standards:

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. DOI: 10.1520/C1615-05.

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.

- NEMA MG1** Motors and Generators³
AGMA 390.0 American Gear Manufacturers Association, Gear Handbook⁴
ANS Design Guides for Radioactive Material Handling Facilities and Equipment, ISBN # 0-89448-554-7⁵
ASME B17.1 Keys and Keyseats⁶
NLGI American Standard Classification of Lubricating Grease⁷
ASME NOG-1 American Society of Mechanical Engineers Committee on Cranes for Nuclear Facilities – Rules for Construction of Overhead and Gantry Cranes⁶
ANSI/ASME NQA-1 Quality Assurance Requirements for Nuclear Facility Applications⁸
ANSI/ISO/ASQ Q9001 Quality Management Standard Requirements⁸
NCRP Report No. 82, SI Units in Radiation Protection and Measurements⁹
ICRU Report 10b Physical Aspects of Irradiation¹⁰
CERN 70-5 Effects of Radiation on Materials and Components¹¹
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 **C859** and **E170**.

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, E170**

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. **C1554**

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 not effective moderators.

³ Available from National Electrical Manufacturers Association (NEMA), 1300 N. 17th St., Suite 1752, Rosslyn, VA 22209, <http://www.nema.org>.

⁴ Available from American Gear Manufacturers Association (AGMA), 500 Montgomery St., Suite 350, Alexandria, VA 22314-1581, <http://www.agma.org>.

⁵ Available from ANS, 555 North Kensington Avenue, LaGrange Park, Illinois 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 American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036, <http://www.ansi.org>.

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, 732 N. Capitol St., NW, Mail Stop: SDE, Washington, DC 20401, <http://www.access.gpo.gov>.

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. **E170**

(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 judgment 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. **C1533**

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. **40CFR 260-279**

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.

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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.

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 • High starting torque • Generally fixed speed, but variable speed can be achieved by using variable freq.drive (VFD) • Reversible • Requires three-phase source
DC brush (permanent magnet)	1/16 - 1	1" – 8"	Variable speed drives, mixers, conveyors, high torque small gearmotors	• Can be low voltage • Variable speed • Non-precision positioning • Brushes may require replacement with high altitude brushes for longer life • Inexpensive motor and controller • No position feedback
DC Brushless – (permanent magnet/servo)	1/32 - 5	1" - 8"	High torque small gearmotors, robotics, linear actuators	• Compact • Precision positioning • Velocity control • Can be low voltage • Long life in high radiation fields if the drive electronics are moved out of cell • Expensive • Reversible
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 • Low efficiency • Brushes may require replacement if motor is used in low moisture or inert gas environment • Normally powered by 120 VAC • Inexpensive

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.

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.