Designation: C1661 – 07

Standard Guide for Viewing Systems for Remotely Operated Facilities[1]

This standard is issued under the fixed designation C1661; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 *Intent:*

1.1.1 This guide establishes the minimum requirements for viewing systems for remotely operated facilities, including hot cells (shielded cells), used for the processing and handling of nuclear and radioactive materials. The intent of this guide is to aid in the design, selection, installation, modification, fabrication, and quality assurance of remote viewing systems to maximize their usefulness and to minimize equipment failures.

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

1.1.3 This guide is intended to apply to methods of remote viewing for nuclear applications but may be applicable to any environment where remote operational viewing is desirable.

1.2 *Applicability:*

1.2.1 This guide applies to, but is not limited to, radiation hardened and non-radiation hardened cameras (black- and-white and color), lenses, camera housings and positioners, periscopes, through wall/roof viewing, remotely deployable cameras, crane/robot mounted cameras, endoscope cameras, borescopes, video probes, flexible probes, mirrors, lighting, fiber lighting, and support equipment.

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

1.2.2.1 The remote operation facility that contains a significant radiation hazard to man or the environment.

1.2.2.2 The facility equipment can neither be accessed directly for purposes of operation or maintenance, nor can the equipment be viewed directly, for example, without shielding viewing windows, periscopes, or a video monitoring system.

1.2.2.3 The facility can be viewed directly but portions of the views are restricted (for example, the back or underside of objects) or where higher magnification or specialized viewing is beneficial.

1.2.3 The remote viewing equipment may be intended for either long-term application (commonly, in excess of several years) or for short-term usage (for example, troubleshooting). Both types of applications are addressed in sections that follow.

1.2.4 This guide is not intended to cover the detailed design and application of remote handling connectors for services (for example, electrical, instrumentation, video, etc.).

1.2.5 The system of units employed in this guide 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. Some video parameters use traditional units that are not consistent with SI Units but are used widely across the industry. For example, video image format is referred to in "inch" units. (See Table 1.)

1.2.6 Lens and lens element measurements are always in millimeter (mm) units, even where SI Units are not in common usage, as an industry practice. Other SI Units (for example, cm) are rarely used for lenses or lens elements.

1.2.7 Unless otherwise mentioned in this guide radiation exposure refers to gamma energy level in terms of ^{60}Co exposure, and radiation per hour or rad/h refers to instantaneous rate and not cumulative values.

1.3 *User Caveats:*

1.3.1 This guide does not cover radiation shielding windows used for hot cell viewing. They are covered separately under Guide C1572.

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

1.3.3 The guidance set forth in this guide relating to design of equipment is intended only to inform designers and engineers of these features, conditions, and procedures that have been found necessary or highly desirable to the design, selection, operation and maintenance of reliable remote viewing equipment for the subject service conditions.

1.3.4 The guidance set forth in this guide results from operational experience of conditions, practices, features, lack of features, or lessons learned that were found to be sources of operating or maintenance problems, or causes of failure.

[1] This guide is under the jurisdiction of ASTM Committee C26 on Nuclear Fuel Cycle and is the direct responsibility of Subcommittee C26.14 on Remote Systems.
Current edition approved Feb. 1, 2007. Published April 2007. DOI: 10.1520/C1661-07.

1.3.5 This guide does not supersede federal or state regulations, or codes applicable to equipment under any conditions.

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

2. Referenced Documents

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

2.2 *ASTM Standards:*[2]

C1217 Guide for Design of Equipment for Processing Nuclear and Radioactive 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

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

2.3 *Other Standards:*

ANS 8.1 Nuclear Criticality Safety in Operations with Fissile Materials Outside Reactors[3]

ANS Design Guides for Radioactive Material Handling Facilities & Equipment, ISBN: 0-89448-554-7[3]

ANS Glossary of Terms in Nuclear Science and Technology (ANS Glossary)[3]

ANSI/ASME NQA-1 Quality Assurance Requirements for Nuclear Facility Applications[4]

ISO/TC 85/SC 2 N 637 E Remote Handling Devices for Radioactive Materials—Part 1[5]

ANSI/ISO/ASQ Q9001 Quality Management Standard Requirements General Requirements[6]

NEMA 250 Enclosures for Electrical Equipment 1000 Volts Maximum (Type 4)[7]

NFPA 70 National Electric Code[8]

NCRP Report No. 82 SI Units in Radiation Protection and Measurements[9]

ICRU Report 10b Physical Aspects of Irradiation[10]

2.4 *Federal Standards and Regulations:*[11]

10CFR50 Appendix B, Quality Assurance

10CFR830.120 Quality Assurance for Nuclear Facilities

10CFR835.1002(b) Continuous Occupancy Radiation Environments

29CFR1910 Occupational Safety and Health Standards

47CFR All Parts—Telecommunications Regulations

40CFR 260-279 Solid Waste Regulations—Resource Conservation and Recovery Act (RCRA)

15CFR, Chapter VII, Subchapter C, Part 774, Supplement 1, Department Of Commerce, Export Administration Regulations

3. Terminology

3.1 *Definitions—General Considerations:*

3.1.1 For definitions of general terms used to describe nuclear material hot cells, and hot cell equipment, refer to terminology in Guide C1533, ASTM/IEEE SI 10, and ANS Glossary of Terms in Nuclear Science and Technology.

3.2 *Definitions:*

3.2.1 *absorbed dose*—Absorbed dose is 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**

3.2.2 *achromat*—a lens, usually of two elements, that is corrected to bring two different wavelengths to a common focal point. A single element lens can only bring one wavelength to a focal point and therefore exhibits chromatic aberration (different wavelengths focus at different distances). An achromatic lens provides a first order of color correction.

3.2.3 *activity*—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**

3.2.4 *alpha*—see *radiation*.

3.2.5 *anti-reflection coating*—a process to apply material to the surface of the glass that reduces reflection, and increases the light transmission through the component.

3.2.6 *balun*—for the purpose of this guide, is a type of passive electronic equipment (that is, not requiring power) that is used to interface between balanced and unbalanced video signals. Baluns are used to transition between a coaxial cable

[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 American Nuclear Society, 555 North Kensington Ave., La Grange Park, IL, 60525.

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

[5] Available from International Organization for Standardization (ISO), 1 rue de Varembé, Case postale 56, CH-1211, Geneva 20, Switzerland, http://www.iso.ch.

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

[7] Available from Global Engineering Documents, 15 Inverness Way, East Englewood, CO 80112-5704, http://global.ihs.com.

[8] Available from National Fire Protection Association (NFPA), 1 Batterymarch Park, Quincy, MA 02169-7471, http://www.nfpa.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 (ICRU), 7910 Woodmont Ave., Suite 400, Bethesda, MD 20841-3095, http://www.icru.org.

[11] 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.

and twisted pair wiring in field applications. Baluns are used in pairs on opposite ends of a transmission cable and are similar to transformers except that they operate at video frequencies.

3.2.7 *becquerel (Bq)*—see *activity*.

3.2.8 *beta*—see *radiation*.

3.2.9 *borescope*—a rigid optical device consisting of lenses and a support tube used to obtain external views of the interior of an object, viewed either directly or with the usage of a camera or video device. The view from the tip may be either directly in front of the tube or off axis by the usage of mirrors or prisms. Most borescopes provide viewing through a series of optical lenses and remotely provided lighting (that is, light from operator end to object in question) through a concentric located bundle of fiber optic light guides.

3.2.10 *browning*—the discoloration and darkening of glass to a brownish color due to excessive radiation exposure.

3.2.11 *bubble suit*—a protective plastic suit that covers the entire body and is supplied with breathing air through an attached hose used for personnel entry into contaminated areas.

3.2.12 *camera*—for the purpose of this guide, camera refers to a video type of camera with a continuous output signal of multiple frames per second, typically at standard broadcast frame rates (for example, 30 frames per second for NTSC video or 25 frames per second for PAL video), or may be a different frame rate typical of higher resolution cameras interfacing with a computer and displayed on a computer monitor.

3.2.12.1 *camera lens*—for the purpose of this guide, a camera lens is the optical assembly on the front portion of a camera used to control the image formation on the camera sensor. The lens may be an integral part of the overall camera, mounted within the same housing, or may be a physically separate device that attaches to the front of the camera body. The latter configuration is very common in the application of remote cameras.

3.2.12.2 *camera housing*—for the purpose of this guide, is a protective housing that is used to physically or radiologically protect a camera from the environment, and extend its useful life. In a remote environment, the camera housing will typically be used to protect the camera from process hazards (liquids, dust, temperature, and debris) or from radiological hazards (contamination, or radiation). In radiological contamination environments, a sealed housing may be essential to allow for eventual repair or replacement of internal camera system components, after the latter is removed to a maintenance environment.

3.2.12.3 *camera, non-radiation resistant*—for the purpose of this guide, is a camera that does not have any designed-in resistance to radiation. This type of camera is very commonly used for short term deployment in radiological environments. An application of this type is often justifiable based on lower cost, small size, or other special attributes found in some general purpose cameras.

3.2.12.4 *camera, radiation tolerant*—for the purpose of this guide, is a radiation tolerant camera is defined as one that continues to function after a specified total integrated dose as specified by the manufacturer and provides a defined level of performance at a specified dose rate. This term is sometimes used interchangeable with radiation hardened camera.

3.2.12.5 *camera, radiation hardened*—for the purpose of this guide, this term is used for cameras that withstand a total integrated dose of 5×10^4 gray (5×10^6 rad) based on ^{60}Co gamma (Si). **15CFR, part 774**

3.2.12.6 *camera, remote*—for the purpose of this guide, a camera that has been designed, modified, housed, or otherwise prepared for application in a remote environment. It may not be possible to repair or replace a remote camera without first using some remote means to relocate it to a separate maintenance environment, and means must be provided to accomplish this relocation.

3.2.12.7 *camera, shielded*—for the purpose of this guide, a shielded camera refers to a camera or camera/lens combination that has been housed in a radiologically shielded housing. The additional radiological protection is provided to extend the useful life or radiological resistance of the camera, and may be applied to either a radiation resistant camera or to a non-radiation resistant camera, depending on the application.

3.2.13 *cell*—see *hot cell*.

3.2.14 *chip type camera*—a commonly used term for a video camera that utilizes a solid state integrated circuit sensor to capture an image. The image is captured by an on-chip type conversion of an electrical charge, from light sensitive silicon, to a charge readout section. The term "chip type" or "chip" is used in this guide to represent the entire family of similar technologies that can be related to radiological environments in a common manner. Common types of chip technology are CCD, CID, and CMOS. See *tube camera* for comparison.

3.2.14.1 *CCD chip technology*—CCD stands for charge-coupled device, which was the original chip type technology. It is one of the two main types of image sensors currently used in digital cameras. When a picture is taken, the CCD is struck by light coming through the camera's lens. Each of the thousands or millions of tiny pixels that make up the CCD convert this light into electrons. The accumulated charge at each pixel is measured, then converted to a digital value, and converted to a video signal output. All pixels in a CCD device are processed as a block rather than individually.

3.2.14.2 *CID chip image sensor*—Charge Injection Device (CID) cameras have been in use since the early 1970's, and are currently used by a few suppliers for digital video cameras, because of some special characteristics. The CID has inherent radiation resistant because of method of construction of the chip.

3.2.14.3 *CMOS chip type technology*—Complementary Metal Oxide Semiconductor (CMOS) image sensors are based on integrated circuit technology by the same name and can be fabricated by similar technology, which provides them with significant cost advantages. CMOS image sensors are rapidly becoming the technology of choice for digital imaging in mobile phones and other digital consumer portable products as they offer advantages in size, power consumption and system cost. New high-sensitivity CMOS image sensor technology provides improving picture quality comparable to CCDs. Relative to this guide, there are few CMOS image sensors that are applicable to any radiological applications where high levels of radiation are present.

3.2.15 *Chalnicon*—see *tube type camera*.

3.2.16 *clamp lock pads*—mechanical additions to tools or objects handled by remote manipulators or robots to assist in the proper gripping of the object. These, usually metal, pads are designed to simplify grasping and to prevent accidental release of the object.

3.2.17 *coaxial cable*—a cylindrical video transmission line composed of a conductor centered inside of metallic tube or shield, which serves as a ground reference, separated by a dielectric material and covered with an insulating jacket.

3.2.18 *dose rate*—a quantity of absorbed radiation dose received in a given unit of time.

3.2.19 *dual unit video camera*—a dual unit video camera has the light sensing portion of the video camera (that is, the image sensor and minimal electronics) separated from the major portion of the electronics into two distinct pieces that are connected by a cable. This design is typical of many of the radiation hardened video cameras, since it allows the most radiation sensitive portions to be located away from the hazard. This design usually involves a complex multi-conductor cable between the two portions of the video device that contains electrically sensitive signals.

3.2.20 *EMF*—the common term for electromotive force. For this document it is used in reference to effects, usually undesirable, of electrical and magnetic fields on electronic equipment, by induced voltages or interference.

3.2.21 *endoscope*—usually refers to one of the rigid or flexible viewing probes when used for medical applications. It can refer to a borescope, fiberscope, or videoprobe.

3.2.22 *exposure*—the quotient of the total charge of the ions of one sign produced in air when all electrons liberated by photons in a volume element of air of mass sufficient to completely stop the electrons (charged particle equilibrium). The special unit of exposure is the roentgen (R) defined as 2.58×10^4 coulombs per kilograms of air. **NCRP-82**

3.2.23 *feed-through*—a generalized term used in this guide to mean the devices or techniques used to transition through a wall or boundary. For the purpose of this guide its usage is further restricted to electrical, instrumentation, or video transitions. Usually this involves sealed connectors, plugs, or sockets that are suitable to the environment on the side of the boundary where they are deployed (for example, manipulator compatible connectors on the radiological side of a hot cell boundary).

3.2.24 *fiber optics*—for the purpose of this guide, are a variety of glass or plastic fibers used to transmit light from one end of each fiber, utilizing total internal reflection between the fiber and a thin cladding on the outside of the fiber. They can be used as a random bundle of fibers to transmit light to a desired location (that is, non-coherent bundle), or the used in an arranged pattern of fibers used to transmit an image from a desired location (that is, coherent bundle).

3.2.25 *fiberscope*—a flexible remote viewing device similar to a borescope, using light transmitting fibers. A view is provided to the operator from the remotely located tip through a flexible bundle of coherent fibers, and lighting is provided from the operator to the tip through a separate bundle of non-coherent fibers located in the same flexible sheath. Coherent fiber bundles provide a large number of light transmission fibers in a matrix that matches on both ends, so that an image is transmitted through the bundle. Non-coherent fibers pass a mass of light in a random pattern through the scope.

3.2.26 *gamma*—see *radiation*.

3.2.27 *gate size*—the size of the gates used to construct a chip type of video sensor. The number of gates and the density of gates can have an effect on the radiation hardness of a chip type of sensor. Chip type video sensors are typically connected to a processing chip type that may be of higher density than the sensor chip type.

3.2.28 *gray (Gy)*—see *absorbed dose*.

3.2.29 *hot cell*—for the purpose of this guide, a generalized term that encompasses the various types of heavily shielded radiological processing enclosures serviced by some combination of manipulators, overhead cranes, remote tooling, or through wall devices, as detailed immediately below: The radiation levels within a hot cell are typically 1 Gy/h (100 rad/h) or higher. See Guide C1533 for information regarding general design considerations of hot cell equipment.

3.2.29.1 *canyon*—an extremely large hot cell accessed by a remotely operated bridge crane(s) resulting in a short horizontal dimension over which the crane bridges and a very long orthogonal horizontal dimension to maximize the internal working volume, in some cases hundreds of meters long.

3.2.29.2 *cave*—a cave or high-level cave is an alternate term for hot cells of various size, typically a small scale hot cell.

3.2.30 *image format*—the generalized term for the size of the video sensor area within the camera, and is independent of the type of camera technology. The format size is based upon the maximum diagonal dimension of the sensing area and defines the area of view seen by a particular choice of lens. The actual numerical values of the format size do not correspond to the actual dimensional units given, but rather to a standardize reference originally based on the glass image tubes used. For example a 1 in. image format refers to the active image area on the face of a 1 inch outside diameter on which it was placed, and therefore the diagonal of the image is less than 1 in. Typical image formats are ¼ in., ⅓ in., ½ in., ⅔ in., and 1 in.

3.2.31 *jumper*—as used in this guide, is a remote means of connecting services (for example, electrical, instrumentation, video, water, or process fluids) between two or more points in a remote environment. These specific application built devices are designed to be compatible with the remote manipulation device provided. They are commonly rigid or flexible devices with connection means on the ends that allow simplified and high integrity connections using only the remote means.

3.2.32 *lens elements*—for the purpose of this guide, the individual optical components that are assembled together to make a complete lens (for example, zoom lens). They are either a single glass, quartz, or similar component with optical quality surfaces on both sides, or have two or more such lens components joined together, either with optical cement or are mechanically mounted together.

3.2.33 *lumen*—a unit of measure for the amount of light emitted by a source.

3.2.34 *luminance*—the signal that represents brightness in a video picture. Luminance is any level between black and white. Luminance is identified by the letter "Y".

3.2.35 *lux*—the amount of light per unit area, incident on a surface. 1 lux = 1 lumen per square meter = 0.093 foot-candles.

3.2.36 *mock-up facility*—for the purpose of this guide, a facility used to represent the physical environment of a radiological facility in a non-radiological setting. Mock-ups are full scale facilities used to assure proper clearances, accessibility, or operability of items to be subsequently installed in a radiological environment before they are actually installed. Their usage allows adjustment, corrective actions, training, or quality assurance steps to be made while hands-on operation is still possible.

3.2.37 *mouse*—when used in this guide in conjunction with a crane hook, refers to a small mechanical safety device that is used to prevent the accidental release of a suspended load. A *mouse* is a spring to-close mechanical lever that closes the gap in a crane hook and prevents the loop or bail in the hook from coming out unless the mouse is held open by hand. This type of device is usually required in a personnel occupied work area but is incompatible with a remotely maintained hot cell or canyon, since there is no way to hold the *mouse* open at the appropriate time.

3.2.38 *neutrons*—see *radiation*.

3.2.39 *Newvicon*—see *tube type camera*.

3.2.40 *non-browning glass*—a glass type that resists discoloration due to high radiation exposure. Traditional optical materials have been used that contained a small percentage of cerium oxide to help stabilize the glass from discoloration due to high radiation exposure. More recently a wider variety of optical materials, such as high purity fused silica, have been demonstrated to resist discoloration. In all cases optical materials will remain clear, as opposed to becoming cloudy, but may lose some or all capability to transmit light.

3.2.41 *pixel*—a video term for a single sensing point or image display point in an overall image. The data from a pixel represents the smallest indivisible unit of an image and is represented by a single grey scale or color value for numerical representation.

3.2.42 *radiation hardened device*—for the purpose of this guide, any device designed to withstand greater than 5×10^4 gray (5×10^6 rad) based on ^{60}Co gamma (Si) total integrated dose, to penetrating nuclear radiation, including x-ray, alpha particles, beta particles, gamma rays, and neutrons.

3.2.42.1 *radiation tolerant device*—for the purpose of this guide, is a radiation tolerant device is defined as one that continues to function after a specified total integrated dose as specified by the manufacturer and provides a defined level of performance at a specified dose rate. This term is sometimes used interchangeable with radiation hardened device.

3.2.43 *radiation absorbed dose (rad)*—see *adsorbed dose*.

3.2.44 *radiation*—for the purpose of this guide, defined as the emission that occurs when a nucleus undergoes radioactive decay. Ionizing energy may be emitted from a source in the form of alpha and beta particles, gamma rays, neutrons, and high-speed electrons. **E170**

3.2.44.1 *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.)

3.2.44.2 *beta*—beta radiation is an electron that was generated in the atomic nucleus during decay and has a negative charge of one.

3.2.44.3 *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.

3.2.44.4 *neutron*—neutron radiation is the emission of neutrons resulting from instability in the atomic nucleus. Neutrons have an atomic mass slightly heavier than a proton, but have no electrical charge.

3.2.45 *remotely deployable camera*—for the purpose of this guide, refers to a camera that has been specially packaged and protected to be compatible with being deployed by a remote manipulation device (that is, robot, manipulator, crane, rope, etc.).

3.2.46 *remotely operated facility*—an isolated, shielded, facility where all operations and functions are preformed without direct human contact. All functions within the remote facility are preformed by mechanical, electrical, or fluid (hydraulic, pneumatic, etc.) linkages through a shielding wall(s). For the purpose of this guide a glovebox or similar facility would not be included in this definition. All viewing of operations within a remotely operated facility would utilize windows, or remote viewing as defined in this standard.

3.2.47 *remotely operated viewing*—the viewing devices within a remotely operated facility that are controlled by personnel outside of the isolated portions of the facility, by electrical, mechanical, or fluid (hydraulic, pneumatic, etc.) means. This type of control would typically include, but not be limited to, camera aiming (that is, pan & tilt), lens control (that is, iris, focus, zoom), camera lights, audio, and camera functions (that is, auto/manual iris, electronic shutter, white balance, etc.). **C1572**

3.2.48 *roentgen (R)*—a unit of radiation exposure equal to the quantity of ionizing radiation that will produce one electrostatic unit of electricity in one cubic centimeter of dry air at zero degrees centigrade and standard atmospheric pressure (limited to x-ray and gamma only).

3.2.49 *tube type camera*—a camera that utilizes a thermionic, tube image sensor to capture an image. A tube type sensor has a light sensitive, optically flat, image capturing surface that faces the optics and a scanning electron beam that impinges on the sensor area to read and erase the captured image one pixel at a time. See "Chip type Camera" for comparison.

3.2.49.1 *vidicon imaging tube*—an image sensor tube that uses a photoconductive target. For the purposes of this guide, a vidicon is a tube with an antimony trisulfide target layer.

3.2.49.2 *Chalnicon imaging tube*—an image sensor tube that has a multilayer photoconductive target made of cadmium selenide and calcogenides. Chalnicon was originally a trademark but the holder of that trademark has allowed it to expire.

3.2.49.3 *Newvicon imaging tube*—an image sensor tube that has a multilayer target composed of zinc selenide and zinc cadmium telluride. Newvicon was originally a trademark but the holder of that trademark has allowed it to expire.

3.2.50 *twisted pair*—two conductors twisted together to form a balanced transmission line. A twisted pair exhibits good noise immunity as interference induced into both conductors is can hot celled by the differential receiver.

3.2.51 *videoscope*—for the purpose of this guide, refers to a flexible remote viewing device that has the viewing electronics located, in miniature form, in the tip and is connected to the operator end by internal wires. Lighting is provided by either a non-coherent bundle of fiber optics or by tip located lights.

3.2.52 *video snow*—the generalized term for random electrical noise seen in video signals. This type of interference appears as randomly located dots, either black-and-white or colored dots depending on the type of video sensor, and are evenly spread across all parts of the image.

3.2.53 *vidicon*—see *tube type camera*.

3.2.54 *vignetting*—the optical property where the outer portion of an image is obstructed by the optics within the viewing system resulting in either the loss or the darkening of the outer portion of an image, usually first seen in the corners of a rectangular image. This usually occurs when the optics are not designed to provide a full image for the format of the image sensor (for example, a ½ in. format lens being coupled to a ⅔ in. format image sensor).

3.2.55 *X-rays*—electromagnetic waves or ions not emitted from the nucleus, but normally emitted by energy changes in electrons. These energy changes are generated either by inner electron orbital shell transitions in atoms or in the process of slowing down electrons by collisions with solid bodies such as is done in an X- ray machine.

4. Significance and Use

4.1 *Remote Viewing Components:*

4.2 The long-term applicability of a remotely operated radiological facility will be greatly affected by the provisions for remote viewing of normal and off-normal operations within the facility. The deployment of remote viewing systems can most efficiently be addressed during the design and construction phases.

4.2.1 The purpose of this guide is to provide general guidelines for the design and operation of remote viewing equipment to ensure longevity and reliability throughout the period of service.

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

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

4.2.4 This guide is intended to be generic and applies to a wide range of types and configurations of hot cell equipment and remote viewing systems.

5. Quality Assurance and Quality Requirements

5.1 The manufacturer and Owner-Operator of hot cell equipment should have a quality assurance program. QA programs may be required to comply with 10CFR830.120, ANSI/ASME NQA-1, ISO 9001, or 10 CFR 50, Appendix B, ANSI/ISO/ASQ Q9001.

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

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

6. General Requirements

6.1 *Application:*

6.1.1 References used throughout this section include: Guide C1217, Guide C1554, 10CFR835.1002(b), 29CFR1910, ANS Design Guides for Radioactive Material Handling Facilities & Equipment, ISO/TC 85/SC 2 N 637 E "Remote Handling Devices for Radioactive Materials—Part 1," ANS 8.1.

6.1.2 Only the minimum number of mechanical or electrical components should be placed in a hot cell to allow safe and efficient operation. Unnecessary equipment in a hot cell adds to the cost of operating and maintaining the hot cell and adds to the eventual decontamination and disposal costs of hot cell equipment.

6.1.3 A thorough review of the remote viewing systems necessary for hot cell operations should be performed prior to introducing the equipment into the hot cell. This should include an evaluation of the resolution and quality of views required. The variety of views and magnifications required should also be evaluated. The desired field of view of any viewing device (typically a camera), the distance to the objects of interest (both minimum and maximum), and the required or desired lighting should also be reviewed prior to the selection of equipment. The performance of radiation hardened lenses, in particular the zoom range and the minimum focus distance, is limited when compared to auto-focus zoom cameras, as noted in later sections.

6.2 *Considerations:*

6.2.1 The amount of remote viewing equipment required within a hot cell and the required wiring, between components should be evaluated together. The in- hot cell equipment should be minimized as much as practical since this portion is most susceptible to damage and most difficult to access; however, this should not be at the expense of overly complex wiring since this can be even more difficult to repair.

6.2.2 Materials of construction of remote viewing equipment on the side should be radiation resistant, compatible with the hot cell environment, easily decontaminated, and compatible with other materials with which they are in contact, to the extent possible and where economically feasible.

6.2.3 Wiring between the remote and accessible portions of any viewing system should be simplified, in number of wires and types of wires, as much as possible and wiring-sensitive signals (for example, low level or noise sensitive signals) should be avoided if possible. The simplicity and robustness of the wiring, to and from a remote system, can be a major determinate of the success of an installation. Complex wiring, signals affected by electrical interference, and connectors with large numbers of connection pins, can significantly reduce the usefulness or survival of an installation, and remote maintenance. The remote wiring should be suitable for the life of the facility and, if possible, be remotely replaceable after a facility is in radioactive operation, since the inability to repair non-functional wiring would terminate a remote viewing system. See NFPA 70, 47CFR.

6.2.4 The inevitable remote replacement or removal of remote viewing components should be carefully considered during the design phase. The complexity and fragility of remote viewing systems as compared to more robust items (for example, pumps, motors, etc.) increases the likelihood of failure in any design. Replacement of systems should incorporate mechanical interfaces, and electrical connectors compatible with the manipulation means in a hot cell.

6.2.5 During the facility design phase, the potential need for remote viewing equipment should be carefully considered, so that provisions can be made for its deployment. Such provisions might include mechanical mounting, wall tubes, electrical feed-throughs, brackets, etc. in a potential location for a remote viewing apparatus. These provisions should have a minimal impact on the initial construction, and significantly reduce the difficulty of a remote viewing deployment at a later date.

6.2.6 Multiple remote viewing systems should be standardized as much as possible to minimize expense and improve maintenance. The maintenance of remote viewing systems often requires a pre-staged camera mount with services for connectors, typically assembled and tested in a mock-up facility, to allow rapid maintenance and to minimize the potential for personnel exposure. Standardized designs allow a minimum number of pre-staged mounts to be required and maximizes the speed of repair. The mock-up facility usually provides for a test version of the mechanical and electrical interfaces that are located in the radiological environment where the remote system can be tested. This assures their proper fit, interfacing, operation, and maintenance prior to their actual installation in a hot cell or similar environment.

7. Materials of Construction

7.1 *Material of Construction in Hazardous Environments:*

7.1.1 Remote viewing systems materials of construction should be resistant to the expected chemical and mechanical environment of a hot cell while maintaining radiation hardness appropriate to the application.

7.1.2 The chemical environment of a hot cell is often hostile to exposed components or materials; this includes the usage of aggressive chemicals for decontamination purposes. This problem can be addressed by enclosing a viewing system in sealed, and sometimes pressurized, housings with sealed viewing windows. Typically, glass or fused silica quartz viewing windows can be used with the latter being much more resistant to high radiation. Wiring should be either completely enclosed within housings (note: various methods below) or protected by chemical resistant jackets.

7.1.3 The construction materials used should be resistant to a discharge of the in-hot cell fire suppression system, if present.

7.1.4 The radiation effects on viewing systems involve both the lifetime dosage and the maximum dose rate. Radiation-induced noise at high dose rates can severely degrade the video image, even though the video system may not suffer significant damage over a short period exposure.

7.1.5 Careful consideration should be given to the expected total accumulated radiation dose and maximum dose rates for the specific remote operations to which the viewing systems will be exposed. Often the radiation requirements are over specified due to limited information or assumptions. This can result in considerable increases of system costs or complexity beyond what is necessary.

7.1.6 The radiation resistance of materials is of particular concern in remote viewing systems, due to the wide variety of materials required (for example, electronics, lenses, windows, wiring, motors, limit switches, insulators). All critical materials (that is, those that would cause a system to fail) should be evaluated to determine their suitability for the radiation hardness requirements in a hot cell. If possible, investigate whether irradiation test certificates or reports are available to provide confidence that equipment will survive the environment in- hot cell, or establish a radiation resistance test program for materials used.

7.1.7 High total dose requirements can be accommodated by designing the remotely deployed portion of a viewing system for simplified replacement. The tradeoffs of designing for higher radiation performance versus designing for more frequent replacement should be evaluated for each system.

7.1.8 The energy level of the expected radiation should be carefully considered in all materials and shielding evaluations. The amount of shielding that is effective against high energy radiation (for example, ^{60}Co) is dramatically different than lower energy radiation (for example, ^{137}Cs) and this should be taken into account.

7.1.9 The type of ionizing radiation expected (that is, alpha, beta, gamma, neutron) can also have an unexpected effect on materials of construction. It is well known that the larger radiation particles (alpha or beta) can be easily stopped by thin metallic or non-metallic shielding materials; however, it is often not appreciated that non-metallic shielding materials can be severely damaged in the process. Plastic, elastomeric, rubber, or similar materials can be severely damaged by direct exposure to alpha and beta radiation.

8. Hazard Sources and Failure Modes

8.1 *Remote Viewing Components:*

8.1.1 Remote viewing systems should function acceptably in the presence of a variety of hazards. The best estimates of the nature and severity of these hazards should be determined before remote systems are designed and fabricated.

8.1.2 Radiation hazards can include x-rays, alpha, beta, gamma, and infrequently neutrons. The materials of construction and decontamination techniques should be compatible with the expected types and levels. When neutrons are present the potential for material activation should be evaluated.

8.1.3 Chemical environments are often present in hot cell facilities since they are often used for experiments, specialized processing, or decontamination of equipment. The compatibility of the hot cell chemical environment with the type of viewing system equipment to be used should be evaluated accordingly.

8.1.4 High temperatures and high humidity can be present in some facilities and can have a severe effect on remote viewing systems where electronics are located in the hot cell. The combined effects of temperature and radiation on remote systems, when they occur simultaneously, can significantly shorten the life of equipment.

8.1.5 High levels of vibration and shock can occur in hot cell facilities, since powerful equipment (that is, motors, pumps, cranes, or manipulators) can be in close proximity in a concrete structure. Consideration should be given to the shock loading on a viewing system, during installation, maintenance activities, and during routine operation. Viewing systems installed on moving or vibrating equipment (for example, on-crane mounted remote cameras) must accommodate long term and possible severe shock loading. These factors should be evaluated to determine their effect on remote viewing equipment or steps should be taken to minimize their effects.

8.1.6 High levels of electromagnetic interference, or electrical noise, may exist when high-power equipment is operated and may degrade the performance of the remote viewing system. Image sensor tubes, still commonly used in most radiation hardened cameras, are more sensitive to magnetic fields than solid state image cameras. Many types of variable speed drives can generate very large amounts of electrical noise that can significantly interfere with the low level video signals, typically 1.0 volt peak to peak. Long cable runs can also reduce the quality of video signals and will reduce the fine resolution of this type of signal.

8.1.7 In- hot cell fire suppression equipment discharge on the remote viewing systems can interfere with, or damage, remote viewing systems.

8.1.8 Remote lighting systems can be a significant source of thermal heat and energy that may not be readily apparent, since direct personnel contact will not occur. They should be evaluated as possible sources of ignition, either during normal operation or when damaged, and as a source of thermal damage the camera or other components. Remote viewing systems can be overheated, and shielding windows can be damaged, by lighting systems in close proximity.

9. Contamination Considerations

9.1 *Remote Viewing Systems:*

9.1.1 Remote viewing systems should be designed for routine or eventual decontamination, to accommodate repair or end-of-life disposal. It is suggested that any material, fitting, or component which would be a hazardous waste in accordance with the Resource Conservation and Recovery Act (RCRA) when disposed, be identified and labeled prior to insertion into the hot cell. See 40CFR 260-279 (RCRA).

9.1.2 Smooth surface finishes free of oxidation (for example, polished or electro-polished stainless), and the minimization of crevices will ease decontamination procedures. In facilities where high-energy neutrons are present, materials that can be activated should be minimized (examples include nickels and alloys containing cobalt).

9.1.3 Exposed wire insulators and seals should be constructed of non-permeable materials to minimize the entrapment of radioactive materials.

9.2 *Maintenance:*

9.2.1 Remote viewing systems should be designed for the type of maintenance designated for the facility (for example, gloved hands, full bubble suit, air hoods, or remote manipulator maintenance). Careful consideration should be given to the size and nature of parts that require handling during maintenance relative to the glove or manipulator designed to maintain the system.

9.2.2 Remote electrical connectors, including external and internal types, should be carefully evaluated to determine their suitability. The external types are those that are directly exposed to the environment and must be protected accordingly. The internal types are enclosed with a housing once deployed, such as being captured between mating components, but may be exposed to the environment while in transit, prior to installation.

10. Equipment Selection

10.1 *Cameras—General Consideration:*

10.1.1 Cameras generally use two types of image sensors: tube type and chip type sensors. The tube type have been used for almost all applications of video sensors for longer deployment in higher radiation environments, while the chip type are used in lower radiation environments or for short deployment in high radiation areas. The chip types are considerably more rugged than the tube type and do not require the periodic adjustments that tube types require. However, the chip types are, typically, affected by ionizing radiation at several orders of magnitude lower than tube types. Also, chip types of several technologies display video snow at very low levels of radiation. There is currently at least one exception, CID, to the above where a chip type of camera has been developed for radiation applications, and it is discussed in later sections. See Table 1 for image sensor comparisons.

10.1.1.1 Tube type cameras utilize a scanning electron beam to read the image accumulated on a light sensitive target. Although they are effectively extinct in modern, general

TABLE 1 Comparison of Camera Types and Typical Radiation Hardness Factors
(See Appendix X1 for Expanded Version of this Table)

Feature	Tube Type Dual Unit (Vidicon)	Tube Type Dual Unit (Newvicon/ Chalnicon)	Tube Type Single Unit	CID Radiation Tolerant (Dual Unit)	Shielded CCD/CMOS	CCD	CMOS
Typical Total Integrated Dose of Acceptable Operation	1×10^6 Gy (1×10^8 rad)	1×10^6 Gy (1×10^8 rad)	1×10^5 Gy (1×10^7 rad)	1×10^4 Gy (1×10^6 rad)	1×10^3 Gy (1×10^5 rad)	100 Gy (1×10^4 rad)	100 Gy (1×10^4 rad)
Typical Limit of Radiation Dose Rate for Acceptable Level of Noise	1×10^4 Gy/h (1×10^6 rad/h)	1×10^3 Gy/h (1×10^5 rad/h)	1×10^3 Gy/h (1×10^5 rad/h)	1×10^4 Gy/h (1×10^6 rad/h)	100 Gy/h (1×10^4 rad/h)	100 Gy/h (1×10^3 rad/h)	10 Gy/h (1×10^3 rad/h)

purpose, video cameras, they continue to dominate radiation hardened video cameras. Other sensing technologies, noted below, do not generally have either the ability to survive higher cumulative radiation doses, or the ability to function correctly in high, instantaneous, radiation fields.

10.1.1.2 Chip type cameras, as defined in this guide, utilize a solid state sensor chip type where the light energy is accumulated on a chip substrate, typically silicon, and coupled electronics creates a video signal. The latter is usually accomplished by shifting the accumulated image data from the light sensitive pixels to an equal size region of non-light sensitive pixels for subsequent readout. The growing variety of chip technologies, each of which has different attributes, is beyond the scope of this guide, except for comments concerning three of the most common types that follow.

10.1.1.3 The radiation hardness of higher density solid state technologies is inherently very poor because the solid state gate size is in direct proportion to its radiation hardness within a given technology. Image chips are of ever decreasing gate size, which tends to decrease their radiation tolerance. The typical chip type camera also includes very high density solid state circuitry on one or more processing integrated circuits. These devices will often be of much higher density than the actual image sensor chip and have been seen to be the weakest link in the application of non-radiation hardened chip type cameras to limited service in radiological environments.

10.1.1.4 The CCD and CMOS types of chip type image sensors are generally only applicable to short deployments in limited amounts of radiation due to their limited life expectancy. The differences between the CCD and CMOS technologies involve factors not relevant to their radiological life expectancy, but rather to cost, image quality, etc. factors that go beyond the scope of this document.

10.1.1.5 CID image sensors have been developed to meet several specific technological requirements, such as radiological environments or scientific applications. A limited number of suppliers are currently offering CID based radiation hardened cameras that provide some advantages of chip type image sensors while providing radiological tolerance. Every pixel in a CID array can be individually addressed via electrical indexing of row and column electrodes. Unlike Charge Coupled Device (CCD) cameras which transfer collected charge out of the pixel during readout (and hence erase the image stored on the sensor), charge does not transfer from site to site in the CID array. Instead, a displacement current proportional to the stored signal charge is read when charge packets are shifted between capacitors within individually selected pixels. The displacement current is amplified, converted to a voltage, and fed to the outside world as part of a composite video signal or digitized signal. Readout is non destructive because the charge remains intact in the pixel after the signal level has been determined.

10.1.2 *Image Noise Considerations*—See Table 1 for noise comparisons.

10.1.2.1 Gamma radiation can cause noise (often described as snow) on the video picture. The type of image chip type will determine the radiation level at which image degradation becomes objectionable. However, solid- state sensors typically exhibit snow at much lower radiation rates than tube type cameras, with degradation beginning in the 1 Gy/h (100 rad/h) range, but this can vary widely with chip technology type. Care should be used to assure that an acceptable image will be acquired in higher radiation levels when a solid-state sensor camera is used. The snow effect is only seen while the radiation is present and may not significantly damage the camera. The CCD and CMOS solid state image sensors will sense and display radiation in the form of noise of image video snow at low levels. The CID technology chip cameras are more resistant to image snow than CCD sensors. Qualification testing of a camera should be made with the camera viewing a representative scene while the radiation is present.

10.1.2.2 If a sensitive image sensor tube (for example, a Chalnicon) is exposed to a dose rate of 1×10^3 Gy/h (1×10^5 rad/h) or more, the radiation-induced noise may limit the detail that can be resolved in the picture. If this occurs it will be necessary to move the camera slightly further from the radiation source to reduce the dose rate at the camera. As an alternative, an antimony-trisulfide vidicon tube could be installed in place of the Chalnicon tube. The vidicon tube will produce good pictures at dose rates that exceed 1×10^4 Gy/h (1×10^6 rad/h), but it requires a higher lighting level and has a shorter operational life than a sensitive image tube.

10.2 *Black-and-White versus Color Radiation Hardened Cameras:*

10.2.1 Radiation-hardened cameras are available in either black-and-white or color versions, but the color versions are very limited in availability. As a general guide, black-and-white cameras provide sufficient remote viewing information for hot cell usage. However, color cameras can be useful in hot cells where a distinguishing of colors is useful, such as the identification of substances, location of stains, identifying color coded equipment, etc.

10.2.2 The preferred choice between black-and-white or color cameras for an installation is determined by the image requirements and not cost, since the two are similar in cost.

Color cameras can provide additional information, where helpful for remote operation, where equipment (for example, connectors, guide pins, etc.) have been color-coded during construction and where color provides clues to chemical changes (for example, types of corrosion). Black-and-white cameras can offer several orders of magnitude better light sensitivity, and better resolution. Often a remote facility is constructed entirely of concrete and stainless materials and color may offer only limited advantages.

10.3 *Housing Considerations:*

10.3.1 In situations requiring a longer term installation, the camera, lights, microphone and pan & tilt enclosures should be stainless steel and designed for decontamination. Short term or one-time inspections can be more cost effective if minimal housings are utilized and the camera assembly is considered disposable or "throw away". The radiological requirements of some applications, typically highly contaminated or alpha emitter contaminated environments, make the decontamination and reuse of camera systems very difficult, and a throw away system may actually be lower cost, depending on the video time period.

10.3.2 The disposal cost of the contaminated material needs to be taken into account, and the limitations on disposal because of materials of construction (for example, lead shielding).

10.4 *Testing Considerations:*

10.4.1 It is preferable to select a camera that has been type-tested in a raised ambient temperature (for example 40°C /104°F) with lights at full power and the pan & tilt and lens motors cycled to simulate the required operational life.

10.5 *Telemetry:*

10.5.1 Some cameras incorporate on-board radiation hardened telemetry control. This allows the camera to operate over relatively simple cables. For example, a pan, tilt, zoom camera can operate through three twisted pairs of wires. Some camera systems have the advantage of using twisted pairs instead of coaxial components within the cable, and the choice of coaxial or twisted pair technologies is independent of the tube versus chip type camera technologies. Coaxial components are typically the most vulnerable to radiation damage and are more difficult to produce in radiation hardened configurations.

10.6 *Wiring and Connections:*

10.6.1 Dual unit video cameras achieve radiation hardness by separating the camera into two distinct sections, the image sensing, or front section, and the controls section, which are connected by a multi-conductor cable. The camera front section, which includes the lens section, is radiation hardened by minimization and selection of components. The controls section is not radiation hardened and is directly accessible by the operator. To achieve this design a larger number of conductors are typically used to connect the remotely located front section and the controls sections, than would be required in single unit cameras. This cabling includes more sensitive signals and specialized conductors than would be required in single unit cameras, this includes signals that would otherwise be handled internally. In all camera installations, and especially in the dual unit cameras, the signal conductors from the radiation area to the non-radiation area may be problematic. These conductors must be accommodated through the signal paths used for the overall installation, such as sealed, or remotely operated connectors.

10.6.2 Radiation tolerant cameras that can withstand the highest total dose are dual-unit configuration. Radiation tolerant single unit cameras are available but generally withstand lower total dose. In the dual units some electronic circuits have to be within the camera for good video performance, with the remaining electronic circuits external to the radiation environment. The single unit cameras have all circuitry in the radiation environment and have simplified wiring.

10.6.3 Coaxial cables are used with most remotely located cameras. The coaxial cables were traditionally made with a solid center conductor when run as a separate cable (that is, not in a composite special made combined cable). Field experience has shown that a stranded center conductor is far superior in life expectancy for coaxial cables, with no loss in signal quality. They should be used for all remote installations that utilize coaxial cables, including radiation and non-radiation hardened camera installations. A number of manufacturers can supply this type of cable and it should be considered for all remote or severe service installations.

10.6.4 Some manufacturers are converting to the transmission of video signals over twisted pairs of wires, rather than relying on coaxial cable, particularly when the application is for high radiation levels. It has been difficult to procure flexible coaxial cables rated to the high radiation level of 1×10^6 Gy (1×10^8 rads) cumulative dose. If twisted pair transmission of video signals is used, the proper interfacing of the signal at both ends of the twisted pair must be provided for acceptable video quality. This typically involves a pair of impedance matching balun transformers, one at each end. Also, the manufacturers' requirements on the twisted pair are significant and must be followed carefully.

10.6.5 All implementations of remotely located video systems require specialized cables that are matched precisely to the requirements of the particular video system, regardless of the type of camera or method of signal transmission chosen. The particular camera manufacturer's cabling requirements should be followed very carefully. Typically, video signals, synchronization signals, control voltages, or power currents cannot be transmitted more than 30 m (100 ft), without degradation. Additionally, the camera signals tend to be very susceptible to EMF noise, ground loop voltages, etc. and must be both carefully shielded and isolated. The dual unit video cameras are particularly susceptible to these problems but all installations can have the potential for signal noise or interference problems.

10.7 *Cameras, Radiation Hardened, Tube Type - Black-and-White and Color:*

10.7.1 Radiation hardened video cameras are suitable for radiation environments that result in long-term cumulative radiation levels and/or where the instantaneous radiation levels are high. They are, typically, significantly more expensive, larger, and lens limited (that is, limited choices of lenses and zoom ratios) as compared to the non-hardened cameras. Cameras of this type have been tested and proved to continue