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

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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 absorbed radiation dose Gy/h (rad/h) refers to instantaneous rates 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/C1572M.

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.

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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, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.5 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

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/C1572M 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 *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.

3.2.2 *activity, A, $[T^{-1}]$, n*—the measure of the rate of spontaneous nuclear transformations of a radioactive material. The SI unit for activity is the becquerel (Bq), defined as one 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 *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 and twisted pair wiring in field applications. Baluns are used in

[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, Two 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.

pairs on opposite ends of a transmission cable and are similar to transformers except that they operate at video frequencies.

3.2.4 *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.

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

3.2.6 *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.

3.2.7 *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.

3.2.7.1 *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.

3.2.7.2 *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.

3.2.7.3 *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.

3.2.7.4 *camera, radiation tolerant*—for the purpose of this guide, 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 interchangeably with radiation hardened camera.

3.2.7.5 *camera, radiation hardened*—radiation hardened TV cameras, or their lenses, that are specially designed or rated as radiation hardened to withstand a total radiation dose greater than 5×10^4 gray (5×10^6 rad), based on silicon, without operational degradation. **15CFR, part 774**

3.2.7.6 *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.

3.2.7.7 *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.

3.2.8 *cell*—see *hot cell*.

3.2.9 *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 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.

3.2.9.1 *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.

3.2.9.2 *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 some inherent radiation resistance because of method of construction of the chip. CID image sensors designed to have increased radiation tolerance are available.

3.2.9.3 *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.

3.2.10 *CMOS-HR CMOS-HR*—for the purpose of this guide, is a type of a CMOS image sensor technology that has been tested and proven to have approximately ten times higher radiation tolerance than typical CMOS or CCD image sensors.

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

3.2.12 *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.

3.2.13 *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.

3.2.14 *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.

3.2.15 *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.

3.2.16 *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.

3.2.17 *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**

3.2.18 *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).

3.2.19 *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).

3.2.20 *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.

3.2.21 *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.

3.2.22 *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.

3.2.22.1 *canyon, n—in the nuclear industry*, a long, narrow, remotely operated, radiological facility.

3.2.22.1 *Discussion*—A large, heavily-shielded facility where nuclear material is processed or stored.

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

3.2.23 *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.

3.2.24 *image delay*—a delay between the sensing and the receipt of a video image due to video encoding and transmission methodology. Depending on encoder and network configuration, the delay (or latency) may be variable. This typically occurs with usage of Internet Protocol (IP) transmission.

3.2.25 *internet camera*—an alternative term for the Internet Protocol (IP).

3.2.26 *IP camera*—an IP camera (Internet Protocol camera) is a type of digital video camera commonly employed for surveillance, and which unlike analog closed circuit television (CCTV) cameras can send and receive data via a computer network and the Internet.

3.2.27 *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.

3.2.28 *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.

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

3.2.30 *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".

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

3.2.32 *megapixel camera*—a megapixel camera is a generalized term for a video camera with a one million pixel, or more, image sensor, as opposed to a traditional video sensor with approximately 400 000 pixels. Typical sensors have 3, 5, 10, or more megapixels. Megapixel sensor images are not compatible with traditional video equipment.

3.2.33 *megapixel lenses*—a megapixel lens is a generalized term for a camera lens that is compatible with the image quality requirements of a megapixel camera. Higher resolution image sensors require the use of higher performance lenses to avoid noticeable distortions and aberration in the image.

3.2.34 *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.

3.2.35 *Network Video Recorder*—a Network Video Recorder (NVR) is a specially configured computer that includes software to record and playback video transmitted over a network. The video images are stored as data on a disk drive or other mass storage device.

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

3.2.37 *non-browning glass*—glass that contains a small percentage of cerium oxide to stabilize the glass and reduce discoloration that would otherwise be caused by radiation. High purity synthetic fused silica is also non-browning, but does not contain cerium oxide, it exhibits almost no discoloration after a high radiation dose.

3.2.38 *NTSC*—NTSC refers to the analog video standard used in North America, Japan, and some other countries. Its usage in this guide is for wired video devices and transmission, and is distinctly different from Digital video or Internet video technology. (See PAL for other counties analog systems).

3.2.39 *PAL*—PAL refers to the analog video standard used in Europe, parts of South America, and many other countries. Its usage in this guide is for wired video devices and transmission, and is distinctly different from digital video or internet video technology. (See NTSC for other countries analog systems).

3.2.40 *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.

3.2.41 *Power over Ethernet*—Power over Ethernet (PoE) describes a group of specifications for equipment that simultaneously passes power and data over wire based Ethernet networks of category 5, or higher. PoE eliminates the need for independent power sources for remotely located video hardware. The offerings from different vendors are not normally interchangeable as the industry standards are still changing, and care should be used to assume compatibility.

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 interchangeably with radiation hardened device.

3.2.43 *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.).

3.2.44 *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 performed 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.

3.2.45 *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/C1572M**

3.2.46 *star network*—star networks, for the purpose of this guide, are internet networks based on a central hub and any number of network links radiating out from that central hub, with no other connections between those links.

3.2.47 *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 line by line. See "Chip type Camera" for comparison.

3.2.47.1 *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.

3.2.47.2 *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.

3.2.47.3 *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.

3.2.48 *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.

3.2.49 *video encoder*—a video encoder is a device that accepts an analog video signal and encodes it into a digital format suitable for connection to an IP network. A video encoder may also support audio (one- or two-way) and bi-directional serial control data. A video encoder may have single or multiple channels.

3.2.50 *video network*—video network, for the purpose of this guide, refers to copper wire, fiber optic, or wireless data networks used to interconnect video cameras, servers, and operator workstations. A video network typically gives priority to video data.

3.2.51 *video server*—video server, in the context of video surveillance, is a specially configured computer on a video network that collects, processes (encodes), and routes video, audio, and control data.

3.2.52 *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.

3.2.53 *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.

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

3.2.55 *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).

3.2.56 *wireless video network*—wireless video networks are wireless implemented versions of a video network. A wireless mesh network has nodes located such that they provide multiple paths. If a path between two nodes is temporarily blocked the signals are automatically routed through nodes that provide an alternative path.

3.2.57 *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, sub-tier suppliers, and Owner-Operator of hot cell equipment should have a quality assurance program (QAP). QA programs may be required to comply with regulations such as 10CFR830.120 and 10 CFR 50 Appendix B, or consensus standards such as ANSI/ASME NQA-1, ISO 9001, or ANSI/ISO/ASQ Q9001, or combinations thereof.

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 Owner-Operator's representative.

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.

6.2.7 Remote video systems for process and anomaly monitoring can be traditional type cameras or IP cameras. Each application should be evaluated for the advantages and disadvantages of each type. There is not a single type that is applicable for all applications. Traditional video cameras typically provide analog video signals (that is, NTSC or PAL) and use multiple wires for power, control, and video. IP cameras typically provide higher resolution and have an Ethernet port for control and video and may also use the Ethernet for power. See later sections of this document for Power over Ethernet, Image Delay, and radiation hardness considerations. A comparison of the pros and cons of both types should be evaluated and include device cost, wiring cost, compatibility with existing systems, resolution required, and lens costs.

6.2.8 Data security and system operability should both be evaluated during design and choice of components in a remote video system. Wired systems typically use a "star" wiring schematic so the system operability is only limited by the wiring provided. IP network systems share singular or multiple IP network wiring with multiple camera, data storage devices, and control points. Additionally the higher resolution cameras require more bandwidth for each device. A system design should take into account the factors of camera resolution, required frame rate, encoding methodology, IP network type (for example, 10BaseT, 100BaseT, 1000BaseT, etc.), and any shared usage of the network. Normally, only the higher speed IP networks can be applied to an IP camera system of more than a few cameras, and a dedicated network may be required to avoid network delays that might otherwise result from shared usage. Wired systems are inherently secure systems, since access is limited by the wiring scheme. However, IP systems must provide measures to prevent unwanted access to the video information. Video management software normally provides several levels of user access by means of usernames and passwords. The levels of access may range from viewing specific cameras, to viewing and controlling any camera, through to administrative rights to change configuration. Restrictions on recording and playback may also be available.

6.2.9 The usage of IP cameras should include an evaluation of the Image Delay relative to the application, since IP cameras and the associated network have an inherent and potentially variable image delay. Image Delay refers to the lag between when an event occurs and when it is available at the operator viewing location. Transmission of signals (video or control) using IP involves the transmission of small data packets, as space is available, on the transmission media and the reassembly of the signals at the receipt end. This methodology has inherent and variable lags. The amount of lag is small for many applications but can be a significant issue for some. For routine surveillance applications the lag is not normally a consideration. However, for any applications where the video image is used for viewing the remote operation of tools the lag can be a significant problem. With a fast dedicated video network the video encoding and decoding time will be the significant part of the delay.

6.2.10 Remote video systems can be either wired or wireless depending on the requirements. The considerations are not related to the above discussion of traditional or IP type cameras, as either can be wired or wireless. The design considerations include cost of wiring, data security considerations, desired camera resolution, required signal bandwidth, and control requirements. If remote camera control is required a bi-directional link is required for wireless systems. Nuclear environments typically have large amount of steel (rebar in walls) and thick concrete that make wireless links challenging. Image quality can be variable and control can be a significant problem due to signal attenuation and multiple reflections. A wireless mesh video network has considerable advantages in this environment due to the flexibility of the mesh to compensate for multipath reception and temporarily blocked paths between nodes.

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 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.

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	CMOS-HR	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)	3×10^4 Gy (3×10^6 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)	1×10^3 Gy/h (1×10^5 rad/h)	1×10^3 Gy/h (1×10^5 rad/h)	100 Gy/h (1×10^4 rad/h)	10 Gy/h (1×10^3 rad/h)	10 Gy/h (1×10^3 rad/h)

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. The radiation tolerance of both technologies varies. The total dose to failure of typical CCD image sensors varies from a few tens of grays to several hundred grays (from a few kilorads to several tens of kilorads). The total dose to failure of CMOS image sensors varies from a few tens of grays to about one thousand grays (from a few kilorads to about 100 krad).

10.1.1.5 Radiation hardened image sensors have been designed for space program applications. Radiation hardened CCD image sensors have been tested and shown to work after a few tens of kilograys (a few megarads) and radiation hardened CMOS images sensors after a few hundred kilograys (a few tens of megarads). However these image sensors are high cost and difficult to apply to imaging applications in remotely operated facilities due to the support electronics needed. An alternate CMOS technology, CMOS-HR is a CMOS image sensor technology that has been tested and proven to have a radiation tolerance approximately ten times greater than typical CMOS and CCD image sensors.

10.1.1.6 Priority solid state image chips have recently been developed that have been tested to a radiation maximum dosage tolerance to 1×10^6 Gy (1×10^8 rad) with one million pixels. The newness of this technology prevents a further evaluation at this time.

10.1.1.7 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.

10.1.1.8 CCD MegaPixel Image Sensors have one million or more pixels and are used in cameras designed for space, scientific, digital cameras and security applications.

10.1.1.9 CID MegaPixel Image Sensors have one million or more pixels and are mainly used in specialized scientific applications.

10.1.1.10 CMOS MegaPixel Image Sensors have one million or more pixels and have become the most popular image sensor for many applications.

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