Designation: C 1661 – 07

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

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 C 1572.

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,

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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.

1.3.5 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]

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

C 1533 Guide for General Design Considerations for Hot Cell Equipment

C 1554 Guide for Materials Handling Equipment for Hot Cells

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

E 170 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 C 1533, 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

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

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

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

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 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 C 1533 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. **E 170**

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.). **C 1572**

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 C 1217, Guide C 1554, 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

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)

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.

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 to produce an acceptable picture to a total dose of 1×10^6 Gy (1×10^8 rad) ^{60}Co gamma radiation. The tube type image sensor radiation-hardened cameras are more resistant to radiation damage than solid state sensor cameras, but are more fragile and require periodic adjustments to maintain image quality. The tube type cameras are significantly more resistant to image degradation (that is, picture "snow" in proportion to the radiation rate) in high dose rates of radiation (that is, 10+ Gy/h (1000+ rad/h)) compared to solid-state cameras.

10.8 *Cameras, Radiation Hardened, Chip Type - Black-and-White and Color*:

10.8.1 Radiation hardened chip type cameras for either black-and-white or color imaging have recently become available from a limited number of suppliers. Specially selected chip technologies are combined with circuitry to monitor and continually compensate for radiation degradation as it occurs.

The units are dual unit designs with relatively complex cables between the two portions of the camera and are currently rated in excess of 1×10^4 Gy (1×10^6 rad) cumulative dosage of ^{60}Co gamma radiation. A major advantage of this chip design for this service is the inherent ruggedness of the chip type camera as compared to a tube type camera, when used in any remote application.

10.9 *Cameras, Non-Radiation Hardened - Black-and-White and Color*:

10.9.1 Non-radiation hardened cameras that use a solid-state image sensor chip may be appropriate for facilities where the radiation level is relatively low, or the exposure time is short. It should be noted that even very short exposure may not be acceptable in some installations, due to radiation dose rate induced image noise (see section on Image Noise). Cameras of this type typically offer capabilities beyond what is commonly available in radiation hardened cameras, such as low light sensitivity, small size, auto-focus, and much wider zoom ratios. Optional accessories include sealed or ventilated lights, microphone and video/control network interfaces.

10.9.2 Some camera families are designed so that a CCD camera can replace a radiation tolerant camera and operate over the same cable and telemetry system. This is a very valuable consideration in applications where the radiation level is either not known precisely in advance or the radiation levels are expected to vary widely over the life of the facility. Less expensive and more mechanically robust solid-state cameras can be used and replaced at a later date with radiation-hardened cameras only if needed. In this case where the wiring is the same, there is no impact on the facility design. Cameras may also be mixed within the same CCTV system.

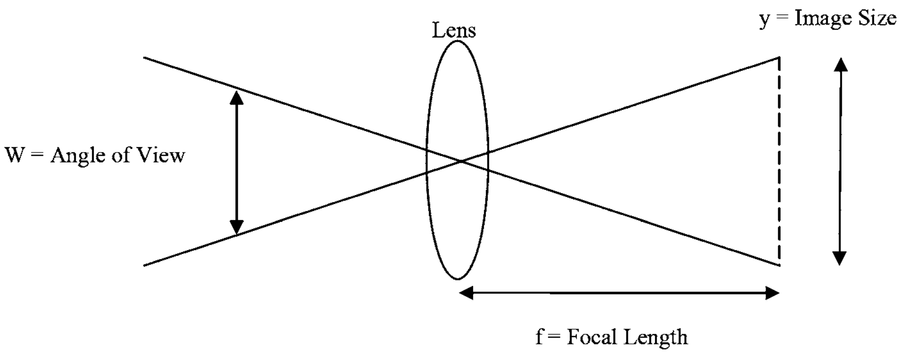
10.10 *Lenses, General*:

10.10.1 The characteristics of video lenses and how they are specified should be carefully considered in any installation, and particularly in remote or radiological installations. All lenses are designed for a particular format video camera and are compatible with that format or any smaller format (for example, a ½ in. format lens is compatible with a ½ , ⅓ , or ¼ in. format camera). Usage with a larger format camera will result in vignetting of the image. Additionally, the quoted angle of view is only indicative for a particular format camera. A camera with a different format will give a different field of view with the same focal length lens. The format of a camera is the diameter of the image circle; this is slightly larger than the diagonal of the image sensor or scanned area of a tube. All camera specification requirements should utilize the desired field of view in horizontal and vertical degrees, to avoid confusion. A comparison of image format, focal lengths and fields of view is shown below in Fig. 1, Table 2, and Table 3.

10.10.2 Commercial motorized zoom lenses intended for security surveillance are often incompatible with close-up viewing often required in hot cells. The lenses are typically designed for focusing from infinity back to 1–2 m (3–6 ft), depending on the manufacturer. This makes close-up work in hot cells difficult. Some radiation tolerant cameras provide a motorized "back focus" capability to overcome this limitation but that adds an additional level of operational complexity as the zoom lens will only track (picture remains in focus as zoom is changed) with the back- focus set correctly. An alternate approach is to add a close-up lens to the front of the motorized lens unit to bring the infinity end of the focus range back to the focus length of the added lens and correspondingly bring the near focus point of the motorized lens closer to the camera. For example, a 1000 mm close-up lens mounted in front of a motorized lens will shift the infinity end of the focus range to 1000 mm and the near focus point closer to the camera.

10.10.3 Achromat lens elements are used to correct for the differences in the focusing of visible light caused by wavelength differences. Any single lens element will focus light across the spectrum (for example, blue to red wavelengths) differently. This makes it difficult, or impossible, to use a single lens element to correctly focus white light. To correct for this optical effect, multiple lens elements are combined that have opposite effects on light of different wavelengths. The elements can be combined mechanically, by closely controlled air spacing, or can be bonded together with optical cement. Acromats are used to correct for focus in both color and black-and-white applications, since sharp focus versus wavelength of sensed light effects both types of applications.

10.11 *Lenses, Radiation Hardened*:



Angle of View (Degrees): $W = 2 \tan^{-1} y/2f$

FIG. 1 Relationship Between Lens Focal Length and Angle of View (Total Angle Shown for a Series of Typical Lens Choices)

TABLE 2 Angle of View Calculation for Typical Lens and Image Sensor Sizes

Lens Focal Length (f)	⅓ in. Format		½ in. Format		⅔ in. Format	
	Horizontal	Vertical	Horizontal	Vertical	Horizontal	Vertical
4.0 mm	62°	48°	77°	62°	95°	79°
8.0 mm	33°	25°	44°	33°	58°	45°
16.0 mm	17°	13°	23°	18°	31°	23°
25.0 mm	11°	8.2°	15°	11°	20°	15°
50.0 mm	5.5°	4.1°	7.3°	5.5°	10°	7.6°
100.0 mm	2.8°	2.0°	3.7°	2.8°	5.0°	3.8°
150.0 mm	1.8°	1.4°	2.4°	1.8°	3.4°	2.5°

TABLE 3 Image Format Dimensions for Common Camera Chip Sizes

NOTE—Image format size refers to industry standard terminology and not actual size. See terminology section for more details.

Image Format	1 in.	⅔ in.	½ in.	⅓ in.	¼ in.
Vertical Distance	9.6 mm (0.38 in.)	6.6 mm (0.26 in.)	4.8 mm (0.19 in.)	3.6 mm (0.14 in.)	2.7 mm (0.11 in.)
Horizontal Distance	12.8 mm (0.50 in.)	8.8 mm (0.35 in.)	6.4 mm (0.25 in.)	4.8 mm (0.19 in.)	3.6 mm (0.14 in.)

10.11.1 Radiation hardened cameras can be fixed or compatible with remote coupling on a pan & tilt unit and offer a choice of fixed focal length and zoom non-browning lenses.

10.11.2 The materials used to make the lens elements will determine the overall radiation hardness of a completely assembled lens, such as a zoom lens or single power lens. As lenses become more complex, such as zoom lenses, the number of lens elements will increase and the effects of the materials of construction will multiply. The materials that have been used to make lens elements and the corresponding generalized radiation hardness are given in Table 4.

10.11.3 The specialized requirements of radiation hardened lenses and the resultant complexity of lens design, especially zoom lenses utilizing the limited range of suitable lens materials, have resulted in a restricted choice of commercially available radiation hardened lenses. The relatively small market for radiation hardened lenses, as compared to non-radiation hardened lenses, makes it impractical for either commercial scale production or wider variety and capability lenses to be developed. These requirements have produced zoom lenses of limited zoom range (that is, ratio of minimum to maximum lens focal length) of typically 6× or less. Radiation hardened lenses are usually designed for operability to a total accumulated dose of 1×10^6 Gy (1×10^8 rads) ^{60}Co gamma radiation, and are typically very expensive. Based on earlier lens technology, the size of radiation-hardened lenses is often, considerably larger than the latest non-radiation hardened variety. Some radiation-hardened zoom lenses, designed for close-up inspection, focus from 50 mm (2 in.) to infinity. The zoom ratio of these lenses is usually 3:1. As a result of the incompatibility of the technology and materials used, it is unlikely that lenses with the performance of solid-state auto focus zoom cameras will be developed.

10.12 *Lenses, Non-Radiation Hardened*:

10.12.1 The large market for industrial grade non-radiation hardened lenses has resulted in a large variety of lens sizes, formats, zoom ranges, and light capture capabilities. Commercially available standard glass lenses are typically useful to 100 Gy (1×10^4 rad) ^{60}Co gamma radiation before the lens elements darken unacceptably, but this can vary widely between lens constructions and the dose rate, and should be verified for the particular lens to be used. Glass that has darkened will slowly and exponentially recovers at ambient temperature. As a result, a lens may be useless after receiving a dose of 100 Gy (1×10^4 rad) in an hour while a similar lens may work acceptably after receiving 1000 Gy (1×10^5 rad) over a period of a year or more. Fixed focal length lenses will typically have higher tolerance to radiation, since they have fewer lens elements.

10.12.2 Lens darkening reversal can be accomplished in some cases based on heat or incandescing light energy. Non-radiation hardened lenses will darken based on their cumulative exposure to radiation. Lens darkening can be reversed considerably if the construction of the lens is compatible with elevated temperatures. Exposure to temperatures of approximately 100°C (212° F) for >1 hour is sufficient to remove most darkening, but some discoloration will remain and full recovery is unlikely. Residual darkening is usually optically clear (that is, like sunglasses) so the lenses may remain useful, if the attached video device has sufficient light sensitivity. Strong visible white light or ultraviolet light, such as concentrated sunlight, can have a similar effect when applicable. In some applications lens darkening reversal may not be a practical alternative, as darkening may occur before useful information can be obtained.

10.13 *Mounted Camera Housings and Positioners* (Pan & Tilt Mounting Assembly):

10.13.1 *General Considerations* (NEMA 250):

TABLE 4 Generalized Effects of Radiation on Lens Elements

Material of Construction	Cumulative Radiation Level Lens Effects and Comments
Plastic Elements—General	Discolor at low levels. Should not be used in any radiological area unless at very low level.
Acrylic	Discolors to light yellow but becomes very brittle. Can only be used at relatively low dose.
Polycarbonate	Discolors to orange after high dose but retains strength.
Commercial Glasses	Darkens by 1×10^2 Gy Use in low level applications only.
Cerium Oxide—Stabilized Glasses	Low refractive index glass shows little discoloration. Higher refractive index glass darkens at high dose rates but shows some recovery when removed from the radiation field. Traditionally used to a total dosage of 1×10^6 Gy (1×10^8 rad). Traditional material for radiation hardened glass. Low refractive index glass is clear, high refractive index glass is yellow.
Fused Quartz—High Purity or UV grade synthetic fused silica	No known upper limit. Tested to greater than 1×10^6 Gy (1×10^8 rad) with no discoloration. Excellent for many applications where its refractive index is acceptable. High purity must be used.
Special Glasses (for example, Proprietary Types)	Vendor Specifications Limited availability but useful for special applications (for example, achromats).

10.13.1.1 Video systems for radiological environments will often require a remote means of installation, removal, and replacement. A specialized mounting arrangement is usually installed, if possible, before the facility becomes inaccessible. The mounting arrangement is typically a very robust mechanical support and alignment guide device with provision for remotely connected services, typically electrical only. This allows all sensitive components to be installed and serviced later by means of an overhead crane, a master-slave manipulator, power manipulator, or crane mounted robotic arm, depending on which has access to the camera system mounting location. A common location for this type of camera system is on the remote crane itself, to guide remote operations of the crane, while other systems are wall or equipment mounted.

10.13.1.2 Remotely deployable camera viewing systems in hot cells or canyons require specialized methods of remote mounting and interconnection to the personnel access areas. These technologies must be compatible with the provided remote handling technology (that is, crane, robot, or manipulator), and they must be sufficiently robust to withstand the radiation, chemical, and thermal environments. Special technologies have been developed to address these needs and should be considered during the design phase, since they can not be easily changed after construction. These techniques will make the largest contribution to the operability of a long term facility, as they will affect how maintenance can be accomplished and how often it is needed.

10.13.1.3 Careful consideration should be given to lighting systems that are incorporated into or directly attached to the camera housing that provide primary and/or secondary illumination. The type of lamp (bulb) and the materials of construction for both the lamp and camera housing (enclosure) need to be carefully evaluated for possible overheating of camera electronics, which could cause premature failure of the camera system resulting in frequent repairs and/or replacement. As an example, quartz halogen bulbs generate very high heat loads that need to be accounted for in addition to camera electronic heat loads when these two items are in a single housing or in close proximity to each other. The materials used in the housing(s) for camera and lighting systems, in addition to the surrounding environment, have a significant impact in providing adequate cooling to the camera electronics. For example, aluminum alloys, are very often used to fabricate camera and light system housings, provide very good heat conduction for cooling purposes to the surrounding environment. However, stainless steel alloys are also utilized for housings where severe environments and/or aggressive decontamination activities may be encountered. Stainless steel alloys tend to be poor conductors of heat and can result in excessive heat loads on camera systems especially when used in non-submerged environments. In these instances, consideration should be given to augment or enhance cooling of the camera electronics by means such as forced convection by the use of purge gas (air), some form of jacketed cooling system, or a pneumatically driven vortex tube cooling system. The intended use of the camera/lighting system also needs to be carefully evaluated since manufacturers supply systems intended for underwater use when the user intends to operate the system in air or a non-submerged environment. For remote deployments, it may be difficult to monitor the heat buildup.

10.13.1.4 Careful consideration should be given to the design of the camera/lighting system(s) to prevent damaging this equipment during installation and/or removal. When installation and/or removal must be accomplished through a riser (pipe) opening or pathway, accommodations in the design should provide methods to prevent the equipment from getting caught or hung-up on sharp edges, protrusions, or other obstacles that could prevent successful deployment or maintenance activities. Consideration should be given to guide type mechanisms to allow successful installation and/or removal of the camera equipment. Also, depending on the type of environment and circumstances of use, consideration should be given to providing some type of decontamination method when removing the camera system for repair or replacement. Decontaminating the camera system as it is removed from service could significantly reduce the contamination levels to the extent that contact maintenance, or disposal at a lower waste category designation, may be possible. The use of spray down wash systems using water, liquid carbon dioxide, and/or decontamination solutions should be considered provided the environment where the camera system is utilized can accommodate this type of activity. The use of materials for camera and lighting systems to support, guide, and hold these items in place during installation, operation, and removal, should be carefully considered from the standpoint of decontamination activities, waste streams generated during life cycle operation, and final disposition after the need for this type of systems is no longer required.

10.13.1.5 Radiation hardened camera and lens combinations are typically much larger than non-radiation hardened combinations, and some types that were specifically designed for reactor core type of inspections have long length to width ratios. Proper allowance for the larger or longer package size should be taken into account during the design phase. Wall mounted or camera systems that pan left and right should especially take into account the longer length or rear entry cable configurations that can interfere with mounting or operation.

10.13.1.6 The pan & tilt configuration typically has internal wiring to avoid any external moving cables, and interconnection points (that is, electrical connector pairs) captured between coupled portions, such as a sealed camera assembly that mates to a sealed pan & tilt assembly. Optional accessories include sealed or ventilated lights, radiation-tolerant microphone and video/control network interfaces.

10.13.1.7 The installation and replacement of remote viewing systems for fixed placement applications requires a precise means of alignment for placing the assembly, methods of connecting the services, and methods of assuring the assembly stays properly positioned during routine operations. Typically, robust dowel or guide pins are used to align the housing with the base, regardless of how the housing is moved into place. A general rule is that the mechanical alignment must hold the housing to the base interface to tolerances tighter than is required by any separately engaged service connections, protecting the latter from damage. The principle is that the robust mechanical portions of the remote connections are of tighter tolerance and alignment criteria than the contained more fragile components, such as electrical pins. The latter are allowed to float sufficiently to ensure they are less sensitive to alignment than the mechanical portions. The result is that either the mechanical components can be assembled with no stress being placed on the internal components, or (in the case of gross misalignment) the mechanical components can not be assembled and the internal components are still protected.

10.13.2 *Crane Accessible Camera Systems*—A typical wall or floor mounted arrangement is shown in Fig. 2 where a permanently installed bracket is equipped with alignment pins and electrical connector. This type of installation is suitable for fully remote facilities where personnel seldom or never enter. The camera housing is positioned on the bracket and is clamped (optionally) onto the bracket. The electrical connection is fully captured between the bracket and installed housing and there are no exposed cables, to provide the maximum protection. This example has a connector in the base of the pan & tilt that aligns and mates with a connector in a wall mount (or floor stand). The camera cable is enclosed within a conduit in the wall-mount bracket. The lifting bail is typically made compatible with either an overhead crane or a manipulator.

10.13.3 *Manipulator Accessible Camera Systems*—The availability of a manipulator or teleoperated robotic device at the camera location provides for several beneficial mounting and maintenance options. The mounting design can allow for a wider range of electrical connection devices, including “push to connect—pull to release” devices typical of a number of manufacturers. Selection of the electrical connectors should take into account that a manipulator can usually only grasp or manipulate something that a person can manipulate using only the thumb and forefinger of one hand. Various remote handling fixtures have been designed and are in use with cameras, with this limitation in mind. Fig. 3 shows a lifting bail with hexagonal bar to ease positioning with a manipulator. The pan & tilt is mounted to a base with a long and a small diameter guide pin(s). The long pin(s) enables easy placement onto a wall bracket or floor stand, and the short pin(s) ensures correct rotational position. Fig. 4 shows an alternate wall mounting approach that minimizes the consumed space from the wall.

10.13.4 *Crane Mounted Camera Systems*—Camera systems that are mounted directly on a remote access crane should be designed to be remotely maintained or replaced, as required, in the facility provided for maintenance of the remote crane. Remote repair or replacement is usually limited to access with a manipulator or crane hook, or to personnel in bubble suits. The latter will have limited dexterity and access time, but do have considerably more handling capabilities than personnel operated manipulators. The camera systems can be secured with quick release fasteners or bolts and a variety of electrical connectors can be used. A typical installation is shown in Fig. 5. As noted in the other types of installations, the cable should be protected and enclosed if possible, and connectors should be robust, as they are very hard to repair or replace remotely.

10.14 *Shielded Housings*:

10.14.1 Camera housings and specialized methods of camera viewing can be an effective method to extend the life of a remote viewing system in a radiation environment. These methods should be used with careful consideration to assure that the resultant shielding is effective for the type and energy of radiation expected and the direction from which the radiation is expected. This applies to the housing material and the required transparent viewing port, as it is almost always beneficial for the housing to be sealed. The amount of radiation expected and the energy level expected should be factored into

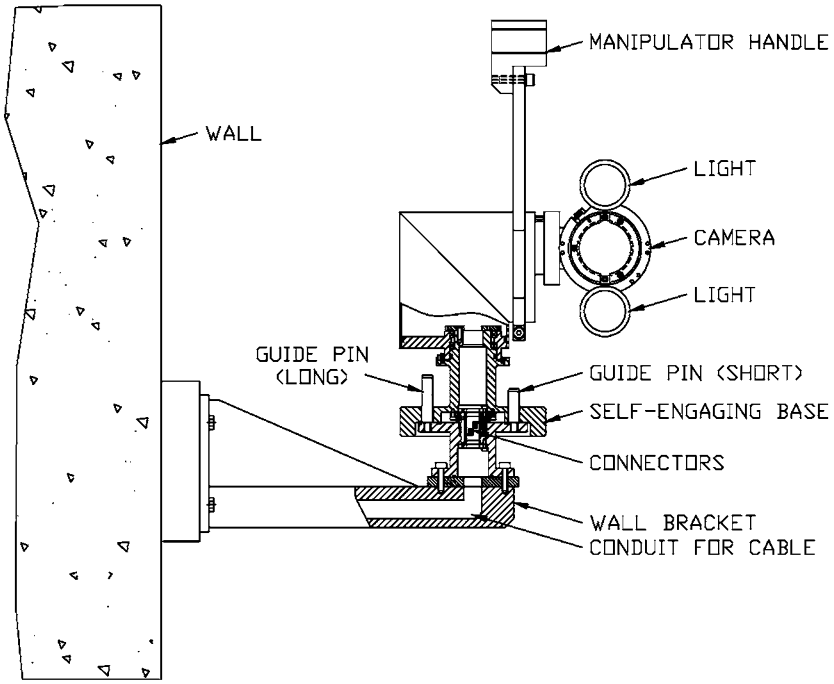


FIG. 2 Typical Wall Mounted Remote Camera Installation (Elevation View)

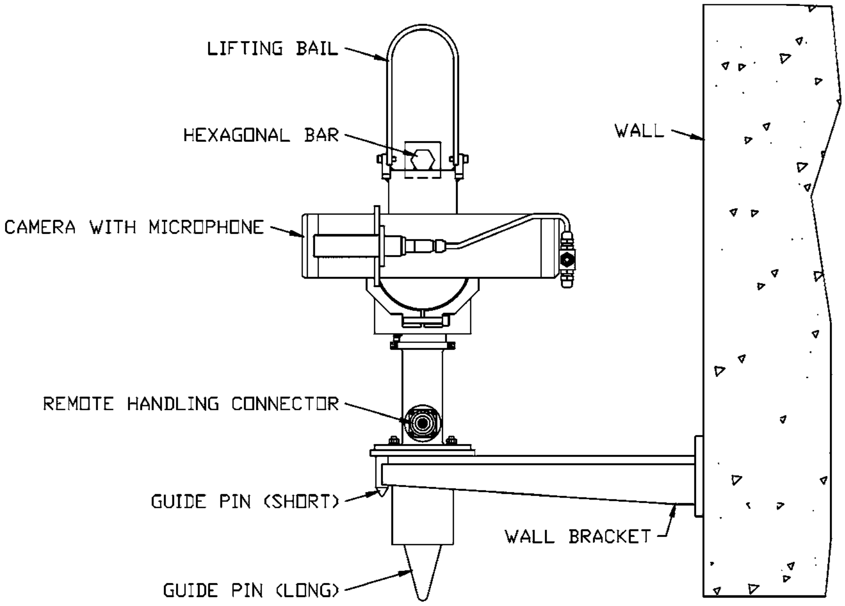


FIG. 3 Typical Manipulator Accessible Camera Installation (Elevation View)

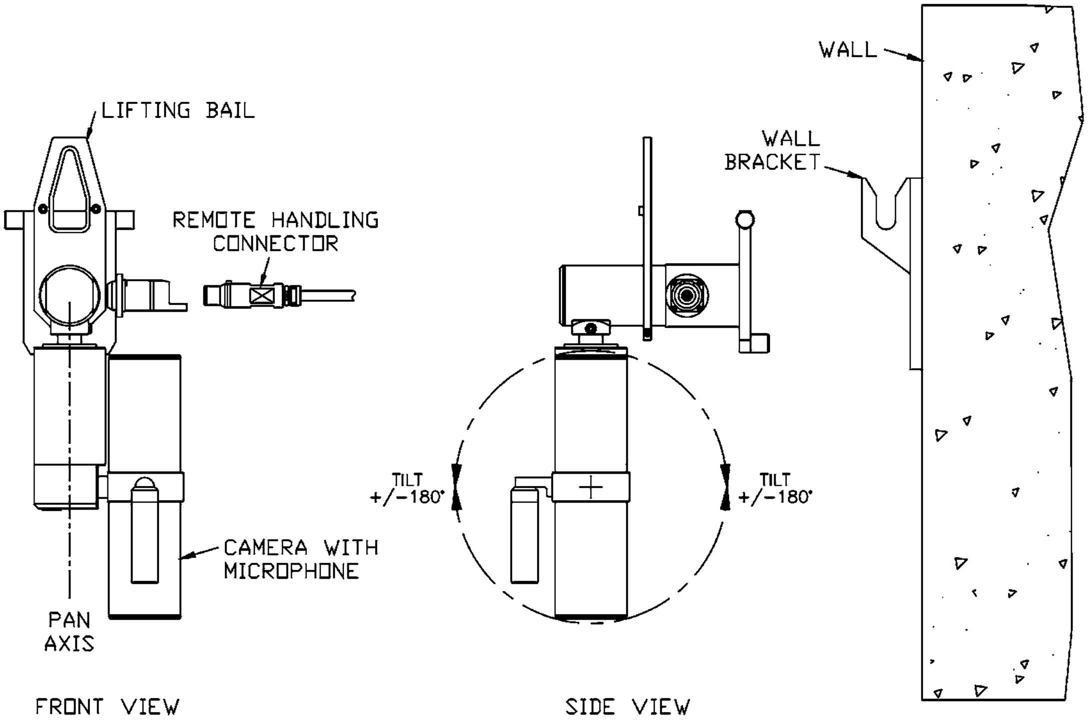


FIG. 4 Wall-Mount Camera Configured for Remote Handling

the types and thicknesses of shielding and/or housings, and the required life expectancy of the system. Shielding can be rated in terms of the amount it will attenuate the incident radiation (tenth thickness), which will be dependent on the energy level. For example: A housing that would be effective against a cesium (^{137}Cs) radiation may be less effective for cobalt (^{60}Co) radiation.

10.14.2 A shielding housing must also factor in the direction radiation is expected to come from. A moveable viewing system, such as a pan/tilt camera housing, must be designed to accommodate the fact that the radiation angles will change continually. Another factor is the presence of large masses of material behind a remote viewing system, such as a camera mounted on a concrete shielding wall. The presence of dense material behind a viewing system may introduce a significant radiation source as radiation that hits the mass will be either reflected or scattered from the mass back in the other direction.

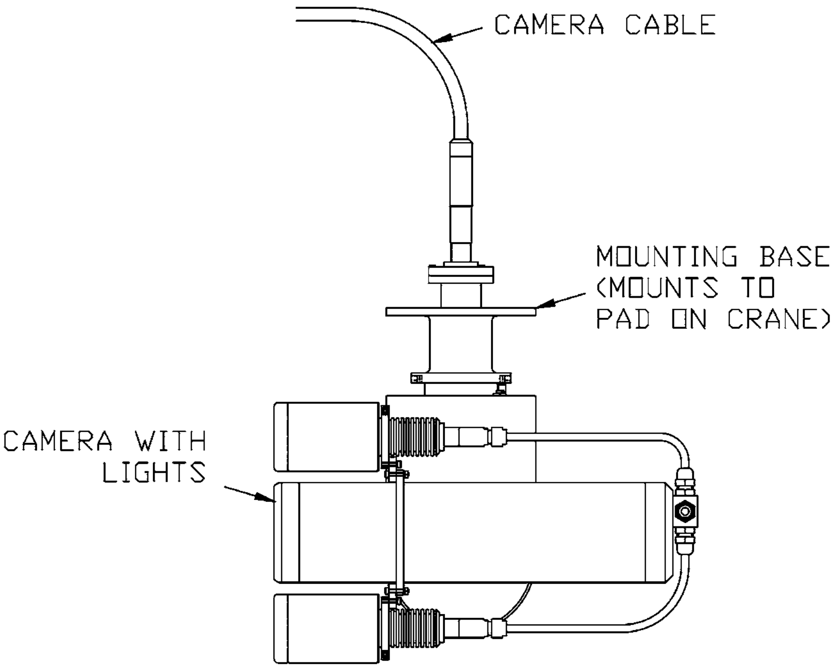


FIG. 5 Typical Crane Mounted Camera Configuration

A camera system mounted against a shielding wall can receive a significant dose from that wall.

10.14.3 The non transparent portions of a housing can be of any appropriate material that will provide the required amount of shielding for the type of radiation expected. Steel housings may be adequate for low energy radiation, thicker or denser materials, (that is, lead or tungsten) may be required for high energy radiation, and special materials, such as plastics for neutrons, may be required.

10.14.4 A shielding housing can use a mirror to offset the angle of view and utilize an appropriately non darkening window that does not itself shield the internal components. The mirror, often a first surface type, will re direct the viewing light while allowing the radiation to pass through.

10.14.5 An alternate method of providing a viewing window is to use radiological shielding glass (for example, leaded glass) as a front mounted view. This would typically be for an application not using a mirror but rather viewing directly out through the shielding glass.

10.15 *Wiring Construction Considerations*:

10.15.1 All wiring connecting a remote viewing system, with the personnel areas, should be simplified as much as possible and be completely enclosed, and have no exposed wiring, if possible. The wiring should be compatible with the radiological and chemical environment. Wire insulation not protected by conduit, or similar, can be susceptible to radiation damage, especially where alpha and beta radiation are present. Published data on wiring tolerance to radiation damage usually addresses gamma radiation only. However, alpha and beta radiation damage can be orders of magnitude higher than gamma radiation when the materials are directly exposed to them.

10.15.2 The configuration of the wiring connecting to a remote viewing system will have a very significant effect on the quality of operation, its survivability, and its repairability. The designer should consider the types of signals used (for example, video signal, synchronization signals, Ethernet signals, etc.), their sensitivity to electrical EMF (which is normally a major concern in a remote facility), and the resultant types of cable required (that is, shielded, twisted, coaxial, etc.). The effectiveness of a remote viewing system may be reduced as the sensitive nature of signals, the number of signals susceptible to interference, and the specialized wiring requirements increase. The size and quality of wires chosen will also affect the long term success of a facility, as smaller wires can be more easily broken in remotely operated connectors. Larger diameter and more flexible wiring (that is, more strands and/or twists per unit of length) is preferred. It has proven difficult to manufacture radiation hardened coaxial cable, which is normally preferred for video or similar signals, that will remain flexible and durable.

10.15.3 The permanent or embedded wiring used for remote viewing systems requires special considerations since it is typically exposed to a higher radiation dose. Because this wiring is not routinely changed when a remote viewing assembly is replaced, and is difficult or impossible to replace remotely, special consideration to its construction is required. As much as practical, embedded wiring that services a remotely positioned viewing system should itself be remotely replaceable during the life of the facility, so that the embedded wiring does not determine the maximum facility life.

10.16 *Connector Considerations*:

10.16.1 The connectors used in a remote environment for viewing systems or any similar application are particularly important to long term success of an installation, and should be addressed early in the design phase. Connectors should be compatible with the expected remote manipulation devices (that is, crane, robot, manipulator, etc.) which normally define the method of connection and release, since all remote manipulation devices have very limited dexterity. Additionally, connectors that are intended to be operated by personnel (for example, connectors on components that are expected to be maintained in a separate remote maintenance facility) should take into account that personnel could be operating through glovebox gloves or be wearing 2 or 3 pairs of gloves. Remote connectors should completely enclose all connector pins and internal wiring and should couple, as much as possible, to metallic conduit or pipes to protect the wiring.

10.16.2 The alignment housing, usually metallic, should have tighter alignment tolerances than the enclosed, more delicate, connector components, pins, and wires. Phrased another way, if the outer housing can be successfully connected, by crane, manipulator, etc., then the internal components should not be stressed beyond their design limits. The alignment of connector halves should be easily confirmed with remote sensing, or remote visual equipment (that is, cameras, windows, etc.) with easy to see markings. Color coding may not be appropriate for many facilities, since most radiation hardened cameras provide a black-and-white picture. It should also be easy to confirm visually when a connector is correctly engaged or locked. It is particularly difficult to visually confirm the locking of many types of snap or locking connectors remotely, but it would normally be easier to confirm proper connection of a latch mechanism.

10.16.3 Mock-up testing of remote housings should be performed in non-radiological facility that is sufficiently similar to the final installation to assure that the proper operation. remote installation, and remote removal can be accomplished in a timely manner. Special attention should be given to all obstructions and inferences that would be present in the final installation that could interfere with potential operational (that is, viewing) and maintenance (that is, installation and removal) operations. Additionally, all remotely installed latches, wiring, or services should be reachable by, and compatible with, the remote installation device (that is, crane, manipulator, etc.) that has been specified.

10.16.4 The detail design of the remote handling connector(s) used to, either connect a remotely located camera to the non hazardous areas, or used to lock the assembly mechanically or a combination connector go beyond the scope of this standard. It is essential that the connectors are compatible with the available remote manipulation means available at the remote camera location relative to their placement, locking, and unlocking design features.

10.17 *Deployment Considerations*:

10.17.1 Remote viewing devices may be deployed by a variety of means (that is, crane, robot, manipulator, etc.), within a given facility. During the design phase, careful consideration should be given to the capabilities of the deployment means when designing the remote viewing system components, including housing, base, locking/clamping mechanism, and electrical connections. The ability to grasp, move, and position remote viewing components requires a compatible means of hooking, and mechanical clamping in place. Combinations of lifting bail attachment points and gripper clamp points are often preferred over single attachment points, to accommodate changing deployment requirements. Special consideration should be given to protecting any portion of the remote device that can be damaged during movement or short term storage in a hot cell type of facility, as some parts, such as electrical sockets, may remain unprotected until a device is installed. Bottom side electrical sockets can be particularly vulnerable to damage when a device in transit is set down.

10.17.2 Deployment locations for a remote viewing system should take into account the required fields of view, magnifications required, distances to objects, and possible visual obstructions.

10.17.3 *Crane Deployment Special Requirements*:

10.17.3.1 Remote viewing packages typically are installed using overhead crane hooks or hooks on other remote equipment, and have robust bails and are handled by devices with open hooks (that is, no hook closing mouse). A major advantage of designing viewing packages for crane deployment is the capability to deploy larger and heavier packages, than can be deployed by force limited manipulators or robots. A corresponding disadvantage of crane deployment is the inability of most cranes to remotely rotate the hooks, although this capability is becoming more common. The designer should take into account the capabilities of the crane to be used.

10.17.3.2 The remote viewing device should be designed for direct vertical placement and should be stable on its support plate when initially released, from the crane, manipulator, etc. Crane deployed devices are often clamped down for stability, but initially there is a delay between release and clamping, during which time the device must remain in position. Devices that require special services to function correctly, such as cooled borescopes or feed tubes, should have a means to protect them during any delays between positioning and engaging of cooling lines etc. A mechanical clamping means is often desired (for example, pan & tilt devices can have a shifting center of gravity during operation) and this can be accomplished by the use of crane hung tools, such as electric impact wrenches, or by manipulators etc.

10.17.3.3 Electrical or other services can be combined with the positioning means or the mechanical clamping means, such as bottom mounted connectors. These engage when the housing is positioned, thus enclosing and protecting the connectors. If separately connected electrical services are used (that is, manipulator connected cables), they should be adequately protected from both the mechanical hazards in a hot cell, or similar, and the radiation and chemical hazards present. As a deployment convenience, crane deployed devices may have lifting bails that fold to one side when released to prevent interference with other devices or allow for connections.

10.17.4 *Manipulator or Robot Special Requirements*:

10.17.4.1 Manipulator or robot positioned and installed devices can be placed in a much wider variety of positions and in more cluttered environments than can crane deployed devices. Also, more sophisticated methods of connecting services can be used. Manipulators and robots may, however, have much more limiting lifting capacities and motion limitations, such as manipulators being limited to a maximum reach from their mounting point. These limitations, particularly weight and maximum force limitations, should be taken into account in the design of a remote viewing device. The need to position a remote viewing device and release it in a stable configuration, prior to any subsequent clamping or locking actions, should be considered in the design phase.

10.17.5 *Tether Deployment*:

10.17.5.1 Tether deployment of remote video systems, where the device hangs from a cable when deployed, is a common and effective method of determining the conditions within a remote hot cell, in support of both routine operations or maintenance activities. A tether deployed camera may be of either a radiation resistant or non-radiation resistant type, depending on the application. Typically since durations are short and cost issues are important to this type of deployment, non-radiation resistant or general purpose designs are used. Additionally, the general purpose cameras may have attributes that provide for better capabilities than are available in radiation resistant units, such as much wider zoom ratios, or unitized pan & tilt packages. The deployment of a camera system by a tether from an overhead crane, manipulator, or similar arrangement can provide a very useful lower level view of a hot cell and see areas that are otherwise obscured from view, to assess conditions. Systems of this type and their tethers should be rugged enough to withstand the expected abuse related to this type of deployment. The system deployed should provide for as simple of a tether design as possible, with a minimum of electrical conductors, to improve the reliability of the systems, and to minimize the tether management concerns. Available technologies can provide a fully functional remote camera system with 4 to 6 conductors utilizing control multiplexing.

10.17.6 *Manipulator Mounted Cameras*:

10.17.6.1 Cameras may be mounted in fixed locations on power manipulators to provide improved manipulator guidance or inspection capabilities. A typical power manipulator arm mounted camera is positioned by the arm movements and can, therefore, be a very simple camera and lens in a housing design, resulting in a small mechanical envelope. Remote means should be provided to remotely replace a power manipulator mounted camera if direct maintenance access is not possible.

10.17.7 *Through-the-Wall or Roof Mounted Systems*:

10.17.7.1 Viewing systems can be installed in through-wall/roof penetrations, as shown in Fig. 7. The camera and positioning unit can be accessed from the non-radioactive area of the facility at any time during operation, simplifying maintenance considerations. A sealing dome is normally left in place at all times as a wall/roof seal while the other components can be removed or replaced. The limitation to an installation of this type is that the viewing location is fixed through the life of the facility and the range of viewing angles is limited. Additionally, this type of installation can be very expensive as compared to other methods.

10.17.7.2 A through-wall/roof camera allows pan/tilt viewing into a hot cell. A prism within a non-browning glass dome tilts and rotates to provide viewing of a hemisphere. The image is relayed through a special endoscope that incorporates shielding to avoid a shine path. As access to the prism drive mechanism involves the removal of heavy components and shielding precautions, it is important that the mechanism be durable and tested to be as maintenance free as practical. The camera module, zoom lens, prism/lens motor drives and video/control interface can be accessed from outside of the hot cell. A through-wall/roof camera is normally installed within a liner system into an encast liner (that is a liner cast into the wall as the concrete is poured). The dome, mounted on the outer liner, provides a seal against contamination and remains in place should the through-wall camera need to be withdrawn.

10.17.7.3 The through-wall camera can be installed into an encast liner of various sizes with a filler liner as shown in Fig.

FIG. 6 Typical Camera On Deployment Tether (Combined Support and Services)

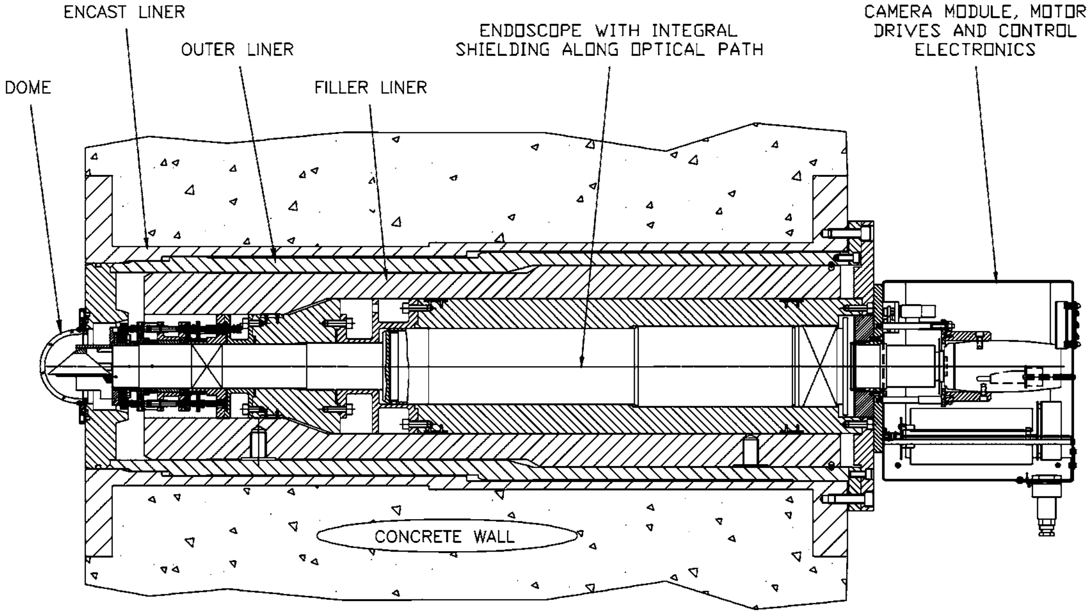


FIG. 7 Typical Through-wall Camera (Cross Section View of Encast Liner and Filler Liner Shown)

7. This arrangement allows the adaptation to a variety of pre-existing wall penetrations where appropriate.

10.17.7.4 The through-wall optical train is modular in construction so that it can be configured to suit the wall/roof thickness and shielding characteristics. Wide and narrow viewing angle variants are available.

10.17.7.5 It is important that the dome sealant be suitable for the environment and has been tested for radiation damage resistance, leakage, and pressure tests. Careful consideration should be given to shielding or sealing of an installed system to protect personnel from radiation, per the vendor's specifications.

10.18 *Radiation Hardened Periscopes* (Direct Eyepiece Viewing):

10.18.1 Remote view periscopes for over wall viewing can be used in cases where the environment will allow their application. The reference here is to the direct human view through optics into a hot cell or similar environment. This type of view is often with either varying magnification or high magnification (for example, remote microscope). Legacy facilities used more periscopes and current deployments should probably be reviewed against alternative devices and the long term availability of systems and parts.

10.18.2 Over the wall periscopes are suited for local viewing applications, since mobility and hot cell contamination control present opposite requirements on their deployment. Most applications should be limited to applications where special attributes are needed (that is, very high magnifications or very high radiation) and cannot be economically addressed with remote video systems. Maintenance of remote viewing periscopes can be a significant issue in any application where contamination is present.

10.19 *Non-Radiation Hardened Endoscope Cameras, Borescopes, and Videoscopes*:

10.19.1 Endoscopes, borescopes, and videoscopes are similar in design and usage but differ in the technology utilized, and each has strengths and weaknesses for differing applications. The probes are small diameter devices of long length best suited to extremely close-up viewing of small objects in confined spaces. Both the rigid and flexible types of scopes are primarily designed for uses other than a radiological environment, and are, therefore, not normally designed for hands on operation and hands on maintenance. They typically can provide very detailed views in confined spaces that can not be accessed by other means, but they can be very expensive, easily broken, and very difficult to decontaminate. Table 5 gives a typical range of sizes and lengths of both flexible and rigid probes, and capabilities currently, commercially, available. Figs. 8 and 9 show typical scope configurations.

10.19.2 *Radiological Concerns*—The non-radiation hardened endoscope, borescope, and videoscope probes are the least tolerant of the remote viewing technologies reviewed in this guide. In high radiation environments, their usage should be of limited durations, as their long length to diameter configuration exacerbate the darkening of the light carrying fibers, used for viewing in some devices and lighting in almost all cases. Also, the tip-mounted electronics in videoscope designs makes them vulnerable to radiation damage. In any radiation environment where contamination is present, these devices can be the hardest to decontaminate of the technologies. The flexible probes have soft or mesh protective jackets that are prone to particle entrapment.

10.19.3 *Lighting*—The lighting requirements of most endoscope, borescope, or videoscope applications are provided by the probe itself. A bundle of non coherent fiber optic fibers is located coaxially around the viewing portion, in most cases, and coupled to an external source of light. Typically a very high intensity light source is coupled through an external fiber optic bundle to the personnel end of the probe, couples to the fibers inside of the probe, and exits at the probe tip. This provides light for near field viewing by the probe (that is, for viewing objects close to the tip). This type of lighting has only

TABLE 5 Typical Commercially Available Rigid and Flexible Endoscopes/Borescopes/Videoscopes

NOTE—All dimensions are in millimeters and not in inches by industry convention.

Type of Scope	Scope Diameter (mm)	Range of Available Lengths (mm)	Articulation in Degrees	Direction of View	Field of View Choices
Rigid	1.2	100 - 230	None	0°	70°
	1.2	96	None	0°, 15°	50°
	2.7	186	None	0°, 15°, 90°	60°, 82°
	2.9	300 - 360	None	0°, 70°	55°
	6	220 - 470	Tip Rotate	0°, 45°, 90°, 120°	20°, 40°, 70°, 100°
	8	242 - 1445	None	0°, 15°, 90°, 120°	10°, 35°, 50°
	16	500 - 1100	Tip Rotate	Variable Span	Variable Zoom
Flexible	0.8	1000	± 90 / ±90	0°	60°
	2.5	750 - 1200	± 90 / ±90	0°	80°
	6	1300 - 7500	±150 / ±150	0°, 90°	40°, 80°, 120°
	8	2000 - 7500	±150 / ±150	0°, 90°	40°, 80°, 120°
	12	1000 - 3000	±130 / ±130	0°, 90°	60°
	8.5	5000 - 30000	None, Guiding Required	0°	100°
	25	30400 - 60960	None, Guiding Required	0°	100°

FIG. 8 Typical Rigid Endoscope or Borescope

FIG. 9 Typical Flexible Videoscope

limited applicability to wide area or long range viewing, and will not usually be acceptable as the only means of light in a large area.

10.19.4 *Rigid Probes*—Rigid probes are typically endoscopic devices that are special application devices built to meet a specific need. They are usually coupled to an externally mounted video camera or viewed directly thorough an eyepiece. They are normally used for a fixed location view of a repetitive application (that is, the same view of the same thing for the same ongoing application).

10.20 *Borescopes*:

10.20.1 Borescopes are a specialized application of a rigid probe that is designed for permanent installation under adverse environmental conditions. They are specific application devices used for severe conditions such as high temperature, high radiation, or adverse chemical environments. As defined here they are designed and built for a single application and are not general purpose devices. They should be pre-qualified to the specific environment or deployment for which they are designed.

10.21 *Flexible Probes*:

10.21.1 Flexible probes (that is, endoscopes, or videoscopes) are typically long devices that only the tip is articulated to provide an off axis view, typically ±180°. The length of the probe must be guided or supported for its deployment to achieve the final point of viewing. They are more suitable to a temporary deployment remote viewing application, as opposed to permanent installation. Deployments of any significant distance should be guided through pipes, ducts, or tubes. These may be existing structures or fixtures based on tubing preinstalled for this purpose. The latter will also minimize contamination of the probe by allowing it to deploy thorough a radiological clean tube.

10.21.2 The flexible endoscopic devices, as defined in this guide, utilize coherent fiber bundles to transmit an image through the length of the probe to the personnel end, where it is coupled to an eyepiece or video camera. A coherent fiber bundle has a very large number of fibers that maintain their relative position from one end to the other, thus transmitting the image projected on one end to the other end. This bundle is in addition to, and separate from, the non-coherent fiber bundle in the same probe used to transmit light solely for illumination. The flexible videoscope does not utilize a coherent image bundle but retains the non-coherent lighting bundle, and a tip mounted video sensor is fitted into the remote end of the probe. The tip mounted image sensor improves the image quality and light sensitivity, and allows longer length probes. The limitations of video probes are the larger diameter required and limitations of the non-coherent lighting bundle to provide adequate lighting.

10.22 *Radiation Hardened Endoscopes, Borescopes, and Videoscopes*:

10.22.1 Radiation hardened scopes have been available commercially from a limited number of suppliers for a considerable time. They have been difficult to deploy remotely due to limitations in flexibility and radiation hardness. Some devices are very stiff with a large bend radius and radiation hardness in field applications has been difficult to maintain.

10.23 *Mirrors*:

10.23.1 Mirrors can be an effective means of redirecting viewing angles in remote location. They are typically used to view otherwise inaccessible areas or, to allow for improved shielding of remote cameras. All of the mirror types discussed below will redirect light (that is, images) while allowing all forms of damaging radiation to pass through the mirror. This allows a camera to be placed at right angles to the remote scene behind appropriate shielding while viewing the scene utilizing a mirror. In this configuration, a large amount of visible opaque radiological shielding material is placed between a source of radiation and the camera without obstructing the mirror based view. Caution should be used in this type of configuration to assure that the camera system can be positioned relative to the source of radiation such that the shielding can be effective without being compromised by camera movement or by radiation scatter from walls or similar.

10.23.2 The mirroring surface of a second surface or normal mirror is of the type that the back side of the mirror reflects light, such that light passes through the mirror substrate. The light passes through the mirror before reflecting off the back of the mirror before passing back through the mirror substrate. This type of mirror is not commonly applicable to a radiation environment, since the substrate must be of a material that does not darken in radiation. Also, a second surface mirror may give inferior image quality when used at an angle, typical of a shielding housing, since a double reflection is seen. Double reflections occur when a portion of the incident light reflects off the front surface of the mirror while the majority reflects off the back or second surface, giving two parallel but offset reflections.

10.23.3 A first surface mirror uses the front surface of the mirror (the first surface light encounters) as the reflective surface, and light does not pass through the mirror substrate. First surface mirrors do not suffer from the double reflection problem of second surface mirrors. This type of mirror is fabricated by depositing a very thin layer of metal on the surface of a glass substrate that has been polished to an extremely smooth (optically flat) surface. The radiation tolerance of the glass substrate to darkening is not a factor as the reflected light does not pass through the glass substrate, even though the glass substrate darkens. The deposited metal is most commonly aluminum, but can be any metal compatible with the wavelengths of light being reflected, such as silver and gold. In all cases, the metal surface must be protected from oxidation and damage, so a thin layer of quartz is typically overlaid on top of the metal. Radiation stability testing with ^{60}Co radiation with the most commonly available first surface mirror material, quartz substrate with aluminum deposit and quartz overlay, have shown no detectable darkening or degradation to 1×10^6 Gy (1×10^8 rad). However, first surface mirrors are much easier to damage mechanically, even with the quartz overlay noted above. Care should be used to prevent breakage or damage from scratching. Cleaning should follow the manufacturer's recommended procedure.

10.23.4 Polished metal mirrors are highly polished metal components where a polished surface or side is used as the mirror. This type of mirror is the most durable of all designs, can be fabricated in shapes, and mounting features can be incorporated into the design. However, an adequate surface finish is also the most difficult to achieve. The quality of the final mirror is limited by the ability of the micro structure of metal to be polished. Metal substrates can not be polished in the same manner or to the same degree as can glass, or similar, substrates. Very limited success has been achieved in producing an adequate surface polish using machine shop technology. Some success has been achieved in producing small metal mirrors using the technology used to prepared metal samples for optical metallurgical analysis. The latter may be limited by the typical small size of this equipment. Metal mirrors have a major advantage in that they are not mounted in the same manner as a second or first surface mirror. A metal mirror is typically a component that is mounted directly (that is, it is threaded or contains mounting studs, etc.)

10.23.5 Hybrid first surface on metal mirrors are a combination of the above technologies that are available from a small number of suppliers. This technology involves the fabrication of a metal component that will be used as the substrate on to which a first surface mirror, as described above, is deposited. The methodology used for depositing the reflective first surface mirror surface on the metal substrate is proprietary. The final result is a metal substrate mirror, with all of the advantages of metal components, and the image quality of a deposited layer first surface mirror, which far exceeds the achievable quality of a polished metal mirror. The reflective surface of the hybrid mirror is susceptibility to mechanical damage, and scratching. Protective measures should be provided.

10.24 *Lighting*:

10.24.1 Lighting is usually required for remote viewing applications, either utilizing previously existing hot cell lighting, or utilizing lighting deployed in support of the remote viewing system. This section of the guide will address the specialized requirements of lighting related to remote viewing. The characteristics of remote lighting may place special requirements on the remote viewing system, if existing hot cell lighting is utilized, or may require special design considerations, if deployed with the remote viewing system.

10.24.2 Spectral considerations can be a factor for any type of remote viewing lighting and the response characteristics of the image sensor in the camera, relative to portion of the spectrum available in the lighting source. For example, the commonly used sodium or high pressure sodium lamps used in hot cells emit light in a very limited portion of the visible spectrum, and can be very incompatible with color cameras, but will work well with black-and-white cameras. Also, the often very high intensity of light in a hot cell may place requirements on the light control portions of more sensitive cameras. Care should be used to assure that any camera system used is compatible with the expected lighting spectrum and intensity expected.

10.24.3 Remote or control lighting, for the purpose of this standard, refers to lighting used and controlled by personnel outside of the hot cell or facility. Remote Lighting, general illumination, requirements involve the minimum lighting required for good image quality, the maximum light expected that the camera and lens must tolerate, and directionality of the lighting requirements. An acceptable amount of light must be available on the remote scene as is needed by the camera system. This also includes lighting in remote positions (for example, under objects, down ducts, or in corners) that will be required to either be available or provided by the viewing system.

10.24.4 Remote lighting, on-camera type, is a very common and effective method to provide the needed lighting for a remote viewing application. This assures that the lighting is compatible with camera and of the proper level of illumination. The primarily considerations are packaging the required lighting in a size and manner that allow remote deployment through the required opening. Lighting can often be as large, or larger, than the related camera system. Additionally, the heat generated by closely attached lighting may be detrimental to the camera system and must be consistent with the specifications of the camera.

10.24.5 Incandescent lighting is very commonly used in remote camera deployments is well known but can be optimized by using halogen or similar type of lights that output more light for the same wattage of regular incandescent light. Also, lower voltage lights, typically 12 or 24 volts DC, have significant better performance in high radiation environments. The thicker and short filaments in low voltage lamps, as compared to higher voltage lamp, are more rugged mechanically and thinner filaments have also been seen experimentally to become more brittle when exposed to high cumulative dosages of adsorbed radiation.

10.24.6 LED Lighting in remote locations is well established as an excellent alternative to other types of lights due to a significantly higher light output for a given input wattage of power and are much more rugged mechanically. It was assumed, due to their method of construction, that they would not perform well in higher radiation dose environments. However, testing has shown that LED's do very well at high radiation dose and survive well in these applications.

10.24.7 Fiber Lighting can be a good option in some types of hot cells where the expected radiation dose is low and the environment (that is, temperature, chemicals present, etc.) it compatible with fiber type lighting. This type of lighting can be fiber optic bundles, liquid type fiber optic bundles, of macro-fiber light pipe. The first two are small, specialized, and more expensive, but may have specialized remote deployment advantages, such as high flexibility or small size. The macro-fiber light pipe is actually a single large clad fiber (typically 10 to 30 mm in diameter (0.4 to 1.2 in.)) that can be useful in many applications, since it is very low cost. In all cases a light source is placed external to a remote location and the light piped into the remote location. This allows for very high intensity light sources that transmit light but not heat into an environment. They are limited as to the maximum distance possible between the light source and the remote viewing location. And the tolerance of the fiber bundle to radiation should be consistent with the remote location environment.

11. Keywords

11.1 borescope; canyon; CCD; CID; CMOS; fiber optic; hardened; hot cell; LED; lens; lighting; mirror; non-browning; pan/tilt; remote; vidicon; viewing

APPENDIX

(Nonmandatory Information)

X1. COMPARISON OF ALL REMOTE CAMERA FEATURES

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
Technology Used	Image Sensor Tube	Image Sensor Tube	Image Sensor Tube	CID Image Sensor	Varies–Chip	CCD Image Sensor	CMOS Image Sensor
Long Term Exposure to Radiation	Long Term OK	Long Term OK	Long Term OK	Medium Term	Depends on Shielding	Short Term Only	Short Term Only
Typical Total Integrated Dose for 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)
Susceptibility to Radiation-Induced Noise (Snow)	Very Low	Low	Low	Very Low	Depends On Shielding	High	High
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)	10 Gy/h (1×10^3 rad/h)	10 Gy/h (1×10^3 rad/h)
Non-Browning Lens Availability	Yes (high cost)	Yes (high cost)	Yes (high cost)	Yes (high cost)	Not Required	Not Applicable	Not Applicable
Relative Cost	Very High	Very High	High	Highest of Chip Types	Camera Low, Housing High	Low	Low
Availability In Color	No	No	No	Yes	Yes	Yes	Yes
Lighting Required	More Than Newvicon or Chalnicon	Low	Low	Medium (High for Color)	Low to Medium Depending on Optics Path	Low to Very Low on Some Models	Low
Size of Deployed Package	Long & Larger Than CCD/ CMOS	Long & Larger Than CCD/ CMOS	Larger Than CCD/CMOS	Biggest of Chip Type	Large and Heavy Depending on Shielding	Small	Small
Type of Wiring Required	Multi-conductor	Multi-conductor	Coax, Power and Lens Control	Multi-conductor	Coax, Power and Lens Control	Coax, Power and Lens Control	Coax, Power and Lens Control