SECTION IX ARMY RADIOGRAPHIC INSPECTION SAFETY

6.9 SCOPE AND PURPOSE OF RADIATION PROTECTION.

6.9.1 General.

a. This section is intended to serve as a guide to the safe use of X-ray and sealed gamma-ray sources for industrial radiographic purposes. It provides guidance to persons who use these sources and to others who may have a responsibility for their use. It recommends operational procedures, personnel controls, and radiation protection practices to eliminate needless exposure of personnel to ionizing radiation. In addition, it provides criteria for the guidance of qualified personnel for the design or modification of industrial radiographic X-ray and sealed gamma ray installations.

b. The word "SHALL" identifies requirements necessary to meet the standards of protection of this section. The word "SHOULD" indicates advisory recommendations to be applied when practical.

c. The provisions of this section incorporate provisions of Title 10, Code of Federal Regulations, Parts 19-21, and 34, and DA documents (AR 40-5, DA PAM 385-24). Although the provisions incorporated herein are correct at the time of issuance, users SHOULD review these federal and Army regulations periodically to assure compliance with current regulations. This section is based in part on recommendations contained in National Institute of Standards and Technology (NIST) (formerly National Bureau of Standards) Handbook 114, *"General Safety Standard for Installations Using Non-Medical X-ray and Sealed Gamma Source, Energies up to 10 MeV"*, in National Council on Radiation Protection and Measurement (NCRP) Report No. 116, *"Limitation of Exposure to Ionizing Radiation"*, and NCRP Report No. 51, *"Radiation Protection Design Guidelines for 0.1-100 MeV Particle Accelerator Facilities" 1 CFR 1020.40 "Safety Requirements of Cabinet X Ray Systems"/ 29 CFR 1910.96 "Ionizing Radiation"*. Exposure limits specified herein are derived from those specified in federal regulations, particularly Title 10, Code of Federal Regulations, (10 CFR) Part 20. In the event of conflict, the more restrictive limits apply.

6.9.2 Responsibilities.

6.9.2.1 Commander. The Commander of each organization/installation using radiation sources or X-ray machines for industrial radiography SHALL:

a. Establish, in writing, a formal radiation safety program consistent with Federal and Army Regulations and with Status of Forces Agreements and assure adequate resources (personnel, materiel, and funding) are provided to implement and maintain an effective program (DA PAM 385-24). This program will include a comprehensive standing operating procedure to provide personnel with clear and specific requirements and actions to assure no person, to include members of the public, receives a dose in excess of the radiation exposure standards specified in DA PAM 385-24 and that radiation exposure in maintained "As Low As Reasonably Achievable" (ALARA). Special consideration SHALL be given to the potential impact on adjacent operations including those operations conducted near boundaries of military control or in leased facilities.

b. Implement and enforce compliance with the provisions incorporated herein.

c. Appoint a qualified Radiation Safety Officer (RSO) and Alternate to perform those functions specified in DA PAM 385-24 and 10 CFR. The authority of the RSO to immediately halt unsafe operations and directly access the Commander SHALL be clearly stated. The training and experience of the Radiation Safety Officer will be commensurate with the hazards and will include a basic understanding of radiation protection principles and practices. As a minimum, the formal training of the Radiation Safety Officer will be successful completion of the Radiological Safety Course presented by the US Army Chemical School or its equivalent (Training required for a RSO to serve as the Radiation Safety Officer for radiography sources licensed by the NRC MAY be much more comprehensive). (Equivalency will be determined by:

Commander
AMCOM, ATTN: AMSAM-SFO-R
5301 Sparkman Center
Redstone Arsenal, AL 35898-5000
Commercial: 256-313-2114, DSN: 897-2114

Pursuant to DA PAM 385-24, or by the Army Radiation Safety Officer). Organizationally, the RSO must be in a position to effectively advise the commander and radiography personnel on matters of radiation protection. Generally, it is not desirable for the RSO to be an operator, supervisor of operators, or under the supervision of such individuals. To provide continuity of operation, an alternate Radiation Safety Officer should also be appointed. Minimum training of Alternate RSOs SHALL be the same as for the RSO. (Personnel from other services or commands such as Health Physicists or Health Physics Technicians can, pursuant to Memorandums of Understanding or Interservice Support Agreements, be authorized to provide radiation safety support for Army units).

d. Implement a radiation dosimetry program in accordance with DA PAM 385-24. As an integral part of the dosimetry program an individual SHALL be designated, in writing, to serve as the dose record custodian to be responsible for preparing and maintaining the records of occupational exposure to ionizing radiation.

e. Appoint a Radiation Safety Committee (RSC) and institute administrative procedures for its operations. (Pursuant to DA PAM 385-24, an RSC is required for all operations such as portable X-rays, where radiation exposures are sufficiently high to mandate dosimetry use).

f. Assure review and approval of plans and specifications for construction of new X-ray facilities or modification of existing X-ray facilities by a qualified expert prior to construction/modification. (NRC licensees must also assure prior NRC approval of all construction and modification activities). Upon completion of construction/modification assure that a comprehensive radiation safety survey is accomplished by a qualified expert prior to operation of the facility.

g. Assure procedures to be followed when an accident or incident occurs are defined, that individuals are designated (in writing) to receive notice in the event of emergencies and that radiation accidents and incidents are reported as specified by AR 385-40 and 10 CFR.

h. Ensure only qualified individuals operate radiographic equipment. A qualified individual is someone who has completed training to qualify for Additional Skill Identifier (ASI) "N2" or attended equivalent training courses conducted by industry or civilian institutions. Qualified individuals SHALL be able to demonstrate competence performing radiographic operations and operating related equipment to include radiation survey instruments. Also ensure operators perform "daily pre-operational, operational, and post-operational checks or surveys to ensure proper radiation safety."

i. Ensure health and safety instrumentation is calibrated in accordance with applicable Army and federal guidance. In accordance with TB 43-180, U.S. Army X-ray survey instruments should be calibrated by the U.S. Army Primary Standards Laboratory Radiation Standards Laboratory (RSL) or other calibration activities authorized by them. The RSL shipping address is:

Transportation Office Central
Receiving, Building 8022
M/F: TMDE Building 5417
Redstone Arsenal, AL 35898
Commercial: (256) 876-0520 / DSN: 796-0520

NOTE

Be sure to notify TMDE personnel the survey instruments are used for industrial X-ray to ensure proper calibration.

j. Perform, and document in writing, an annual quality assurance audit/self-assessment of the organization’s Radiation Protection Program. A quality audit checklist is available upon request from:

Commander
AMCOM, ATTN: AMSAM-SFO-R
5301 Sparkman Center
Redstone Arsenal, AL 35898-5000
Commercial: (256) 313-2114 / DSN 897-2114

k. Designate in writing a qualified radiographer to serve as "Radiography Supervisor" overseeing industrial radiography operations, and assuring compliance with all aspects of the radiation protection program.

l. Assure radiography operations are not conducted on non-Army property without verification such operation is properly licensed by and in full compliance with applicable state and local regulations and laws.

m. Consultant services of qualified individuals are available from the respective AMC Headquarters and from the following to assist with the Radiation Protection Program:

(1) US Army Aviation and Missile Command
ATTN: AMSAM-SFO-R
300 Sparkman Center Redstone Arsenal, AL 35898-5000
Commercial (256) 313-2114 / DSN 897-2114

(2) US Army Center for Health Promotion and Preventive
Medicine ATTN: MCHB-MR-HI
Aberdeen Proving Ground, MD 21010
Commercial (800) 222-9698 / DSN 584-3502

6.9.2.2 Radiation Safety Committee (RSC). The Radiation Safety Committee SHALL perform functions outlined in DA PAM 385-24, and any applicable NRC license.

6.9.2.3 Radiation Safety Officer (RSO). The Radiation Safety Officer SHALL establish and manage the radiation protection program. Specific duties of the RSO, as defined in DA PAM 385-24 include (but are not limited to):

a. Provide advice and assistance to the Commander in formulating policies, programs, and procedures pertaining to radiation protection that complies with applicable regulations and directives. Advise the Commander in writing of any unsafe practices, defects, or noncompliance's under 10 CFR 21.

b. Evaluate and document hazards. "Radiation protection surveys will be performed periodically by the RSO to determine the exposure or exposure rate in the environment during operation of the equipment" as necessary to evaluate and control the potential radiation hazard. This evaluation includes physical measurements or calculations of radiation levels present; a prediction of potential hazards resulting from changes in materials or operations and proposed corrective actions. (Surveys SHALL be accomplished by a health physicist or Nuclear Medicine Science Officer before placing equipment in routine operation for all new or modified industrial radiographic operations.) Consistent with NRC quality audit criteria, surveys SHALL be accomplished at least annually by the local RSO in conjunction with audit of the local radiation safety program. Care SHALL be taken to assure radiation levels are adequately controlled in areas such as roofs, and in rooms and outdoor areas adjacent to X-ray operations.

c. Develop emergency procedures and assure all actual or alleged overexposures to ionizing radiation are investigated and reported in accordance with AR 385-40, DA PAM 385-24 and 10 CFR.

d. Calculate the collective exposure to ionizing radiation of all persons for which a DD Form 1141 (or equivalent) is maintained and report quarterly to the Radiation Safety Committee and commander, as applicable, on the collective, average, and highest exposure.

e. Instruct personnel in safe working practices, emergency procedures, harmful effects of radiation overexposures, and other topics as mandated by 10 CFR 19 and 29 CFR 1910. Records of these instructions will be maintained by the RSO and will include a brief outline of the instructions and a list of persons who received these instruction

f. Establish and maintain a personnel dosimetry program in accordance with DA PAM 385-24 to include obtaining personnel exposure histories and providing personnel with reports of radiation exposures as required.

g. Assign administrative radiation doses.

h. Manage Department of the Army (DA) Radiation Permit program (DA PAM 385-24; 32 CFR 655).

6.9.2.4 Radiography Supervisor. This individual SHALL supervise overall industrial radiography operations and assure compliance with all aspects of the radiation protection program. Personnel SHALL:

a. Control and maintain all industrial radiographic equipment to include assuring the X-ray tube head, cable, consoles and gamma source radiography shielding, and shutters (and the associated safety equipment for each) are checked for obvious defects prior to the first use at the beginning of each shift.

b. Develop and maintain current radiological safety operating and emergency procedures approved by the Radiation Safety Officer and Commander. Safety procedures will specifically address checklists for periodic inspection and reliability testing of safety systems to include interlocks, audible and visual warning devices, use of radiation monitoring equipment, and “daily pre-operational, operational, and post-operational checks or surveys to ensure proper radiation safety. Emergency procedures SHALL include, but are not limited to, the following:

(1) Individuals to contact in the event of overexposure. Include name, office symbol, telephone number (duty and non-duty hours), and duty title.

(2) Notifications required by 10 CFR and/or AR 385-40 and accident incident form to be completed pursuant to AR 385-40, as supplemented.

(3) Where to take the individual for treatment.

(4) How to approximate the degree of exposure.

(5) What to do with dosimetry devices.

(6) A copy of the radiation safety operating and emergency procedures must be maintained with radiation producing equipment during all radiographic operations. These procedures must ensure required warning signs and notices are properly posted and warning signals (beacon lights and audible alarms) and safety switches are functioning properly.

c. Establish and maintain personnel monitoring program in conjunction with the Radiation Safety Officer and assure proper use and storage of personnel monitoring devices.

d. Ensure the availability, calibration, and proper maintenance of radiation survey instruments.

e. Utilization logs SHALL be maintained. Ensure detailed procedures are implemented for maintaining an operational log for each piece of equipment that will identify when interlocks and other control or warning devices are bypassed or overridden.

f. Assume control and institute corrective actions in the event of an emergency.

g. Investigate, in coordination with the RSO, the cause of accidents and incidents to include suspected overexposures and unnecessary radiation exposures, and determine necessary action to prevent recurrence of accidents and incidents. Maintain all radiation exposures "As Low As Reasonably Achievable” (AR 385-40, AR 385-10 and DA PAM 385-24).

h. Verify the competence of radiographers to include ensuring only qualified personnel with ASI “N2” identifier or other acceptable qualifying credentials perform X-ray operations or use X-ray equipment and only individuals authorized by the applicable NRC license use gamma radiography sources.

6.9.2.5 Radiation Safety Monitors. Radiation safety monitors are qualified radiographers who work under the direct supervision of the radiographer in charge. Duties include:

a. Operate radiation survey meters.

b. Establish location of radiation barriers.

c. Set up personnel barriers.

d. Prevent unauthorized personnel from entering a radiation area.

e. Record radiation intensity readings at barriers.

f. Record doses from direct reading dosimeters.

g. Utilize dosimetry devices as specified by the Radiation Safety Officer.

h. Perform other duties as directed by the radiographer in charge.

6.9.2.6 Radiation Safety Monitor Assistants. Radiation Safety Monitor Assistants are those persons who assist the radiographer and/or the Radiation Safety Monitor in preventing unauthorized access into radiographic inspection areas. Duties include:

a. Operate radiation survey meters.

b. Assist with setting up personnel barriers.

c. Prevent unauthorized personnel from entering a radiation area.

d. Wear a TLD or film badge only if specified by the Radiation Safety Officer.

6.9.3 Qualifications of Industrial Radiographers.

6.9.3.1 NAS-410, Nondestructive Testing Personnel Qualification and Certification, as amended, define the minimum qualifications for radiography personnel (including recertification requirements).

6.9.3.2 Qualifications MAY be through the USAF Nondestructive Inspection Course conducted by the Air Education and Training Command at NAS Pensacola, FL, the U.S. Navy Radiographic Operator course (A-701-0032) or through equivalent training courses conducted by industry or civilian institutions. To be considered equivalent to training mandated for American Society of Nondestructive Testing for the Industrial Radiography Radiation Safety Personnel (IRRSP) Certification Program, the initial training SHALL include 40 hours of training in radiation safety topics which includes those topics listed in Appendix A of 10 CFR 34. Equivalency SHALL be reviewed and approved by TRADOC or the Army NDT Center of Excellence Program Manager, AMCOM Corrosion Prevention and Control Program Office, AMSRD-AMR-WD-GA. The use of any radiation producing equipment is prohibited until written approval of equivalency is received by requester.

6.9.4 Industrial Radiographic Safety Training.

6.9.4.1 Initial Training. All industrial radiographers SHALL complete an approved course of instruction in the use of industrial X-ray equipment, which includes radiation hazards control, and demonstrate an understanding of acceptable practice. As a minimum, each radiographer SHALL be instructed in those portions of the following subjects, which applies to industrial radiographic operations and demonstrate understanding thereof.

a. Fundamentals of Radiation Safety.

(1) Characteristics of X-ray and Gamma Radiation.

(a) Electromagnetic Spectrum.

(b) Properties of X-ray and Gamma Radiation.

(2) Interaction of Radiation with Matter.

(a) Ionization.

(b) Photoelectric Effect.

(c) Compton Effect.

(d) Pair Production.

(3) Attenuation of Radiation.

(a) Exponential Function.

(b) Half-Value Layer (HVL) and Tenth-Value Layer (TVL).

(c) Filtration.

(d) Shielding.

(4) Inverse Square Law.

(5) Radiation Scattering.

(a) Secondary.

(b) Sky Shine.

(6) Units of Radiation Measurement.

(a) Roentgen.

(b) Radiation Absorbed Dose (rad), Roentgen Equivalent Man (rem).

(c) Gray (Gy), 1 Gy = 100 rad; Sievert (Sv), 1 Sv = 100 rem.

(d) Exposure Rate and Dose Rate.

(7) Quantity of Radiation.

(a) Curie, Becquerel; 1 Curie (Ci) = 3.7 x 10^{10} Becquerel (Bq).

b. Hazards of Exposure to Radiation

(1) Naturally Occurring Radiation.

(2) Biological Effects.

(a) Mechanism of Tissue Damage.

(b) Variables Influencing Radiation Doses.

(c) Somatic and Genetic Effects.

(d) Occupational Dose Limits.

(e) Non-Occupational/Public Exposure Limits.

c. Radiation Exposure Records.

(1) Prior Exposure History.

(2) Reports of Radiation Exposures.

d. Radiation Measurement.

(1) Principles of Radiation Measurement.

(a) Energy Dependence.

(b) Response Time.

(c) Ionization Chamber Instruments.

(d) Geiger-Mueller Instruments.

(2) Direct Reading Dosimetry.

(a) Use of TLD (or film) Badges.

(b) Pocket Ion Chambers (Pocket Dosimeters).

(c) Alarm Devices/Rate Meters.

(3) Survey Meters.

(a) Meter Differences.

(b) Meter Operation and Calibration.

(c) Meter Capabilities and Limitations.

(d) Survey Techniques.

e. Radiation Protection.

(1) Control of Radiation Dose.

(a) Dose Rate Factors (X-ray and/or Gamma Radiation).

(b) Exposure Time.

(c) Exposure Distance.

(d) Shielding.

(2) Safety Equipment for Unshielded Operations.

(3) Safety Equipment for Shielded Operations.

f. Practical Application Requirements.

(1) Choosing Radiographic Equipment to Use.

(2) Radiation Exposure in Shielded Operations.

(a) Accidental Exposure.

(b) Beam Orientation.

(c) Location of Operating Controls.

(d) Checkout of Safety Devices.

(3) Radiation Exposure in Unshielded Operations.

(a) High (and Very High) Radiation Areas.

(b) Placement of Barriers.

(c) Measurement of Exposure Rates.

g. Inspection and Maintenance Performed by Radiographers.

(1) Interlocks.

(2) Warning Devices.

(3) Radiography Equipment/Facilities.

h. Emergency Procedures.

i. Case Histories of Radiography Accidents.

j. Regulations.

(1) Applicable Military Service.

(2) Federal.

(3) State.

(4) Local.

6.9.4.2 Annual Retraining/Retraining/Refresher Training. Each radiographer SHALL receive annual retraining and training each time there is a change in equipment, operating procedures, or regulations. Retraining of at least eight-hours duration (FR Vol. 56, No. 53, page 11505) SHALL be conducted or arranged by the RSO or his/her designated representative and documented. Annual Retraining/Retraining/Refresher Training SHALL include the items identified below. (Note if personnel do not use, possess, or provide direct contract oversight of gamma emitting radiographic sources, 10 CFR training requirements are not required.)

a. Topics specified in 10 CFR 19.12 (e.g., proper storage, transfer, and use of radiation sources, public health problems associated with use of the radiation sources, precautions, or procedures to minimize radiation exposure and the purposes and functions of protective devices employed, the responsibility to promptly report any condition which may lead to unnecessary radiation exposure, actions to take in the event of malfunction of protective devices or other emergency conditions, and exposure reports which workers may request.)

b. Deficiencies identified during periodic quality audits of the radiation protection program and unit training inspections.

c. Review of accidents and unusual events.

d. Review of dosimetry results (emphasizing dose reduction and ALARA).

e. Review of basic radiation safety principles, operations, emergency procedures, new safety regulations, license requirements, and other pertinent information.

f. If a radiographer or a radiographer's assistant has not participated in a radiographic operation for more than three months since the last training inspection, that individual's performance SHALL be observed and recorded the next time the individual participates in a radiographic operation.

g. Retain the training inspection records of the performance of radiographers and radiographer's assistants (for RSO compliance inspection purposes) for three years.

6.9.4.3 Documentation. MOS qualification SHALL be documented in accordance with Army Regulations.

6.9.4.4 Training for Radiation Safety Monitor Assistants. Assistants SHALL receive, as a minimum, radiation safety training covering the following items: properties of X- and gamma radiation, hazards of excessive exposure to radiation, methods of measuring radiation, radiation protection, and operation of specific measurement devices that will be used. This training SHALL be conducted by a qualified radiographer, Bioenvironmental Engineer or Radiation Safety Officer and documented in the individual's training record or the Maintenance Management Information Control System (MMICS). Refresher training SHALL be conducted annually.

6.9.4.5 RSO Retraining. Retraining of at least eight hours in duration SHOULD be completed on an annual basis by all RSOs.

6.9.5 Radiation Protection.

6.9.5.1 As Low As Reasonably Achievable (ALARA). All exposures SHALL be kept "As Low As Reasonably Achievable." Exposure to radiation, even at very low dose rates, is permissible only when the benefit derived from such exposure exceeds the risk incurred. Each individual SHALL strive at all times to maintain all radiation exposures "As Low As Reasonably Achievable." Individuals SHALL NOT ever knowingly expose themselves, or cause others to be unnecessarily exposed to radiation.

6.9.5.2 Radiation Dose Limits.

6.9.5.2.1 Occupational Dose Limits. The annual peacetime ionizing radiation dose received by occupationally exposed adults SHALL NOT exceed the following:

a. An annual limit, which is the more limiting of:

(1) The total effective dose equivalent (TEDE) of 5 rem (50 mSv); or

(2) The sum of the deep dose equivalent from external sources and the committed dose equivalent to any individual organ or tissue, other than the lens of the eye, of 50 rem (500 mSv).

b. The annual limits to the lens of the eye, to the skin, and to the extremities, which include:

(1) An eye-lens dose equivalent of 15 rem (150 mSv); and

(2) Shallow-dose equivalent to the skin or to any extremity of 50 rem (500 mSv).

6.9.5.2.2 Dose Limit for Minors. The annual occupational dose limits for minors (less than 18 years of age) are 10% of the annual occupational dose limits specified for adults.

6.9.5.2.3 Dose Limits for Pregnant Females (Embryo/Fetus).

a. The radiation dose to the embryo/fetus of an occupationally exposed pregnant female SHALL NOT exceed 0.5 rem (5 mSv) for the entire pregnancy. Additionally, efforts SHOULD be made to maintain the exposures ALARA and relatively uniform, that is, free of substantial dose rate variations above monthly exposure rates.

(1) A formal declaration of pregnancy is the prerogative of each pregnant female. A female occupationally exposed to radiation does not fall under the lower dose limit until she formally declares her pregnancy in a written statement.

(2) The declaration SHALL be made on a SF 600 (Health Record—Chronological Record of Medical Care), signed and dated by the woman and placed in the woman's health record. A copy SHALL also be provided to the RSO. An appropriate example of declaration follows:

"I hereby make notification that I am occupationally exposed to radiation in the course of my normal job duties, and that I am now pregnant. My estimated date of conception is_____. I understand that by declaring my pregnancy, my occupational exposure to ionizing radiation will be controlled as prescribed by DA Pam 40-18."

NOTE

If the dose to the embryo/fetus exceeds 0.5 rem (5 mSv) or is within 0.05 rem (0.5 mSv) of this dose at the time the woman declares the pregnancy to the RSO, the organization SHALL be considered in compliance with the limit prescribed above provided any additional dose to the embryo/fetus does not exceed 0.05 rem (0.5 mSv) during the remainder of the pregnancy.

6.9.5.2.4 Dose Limits for Individual Members of the Public. The total effective dose equivalent to members of the public SHALL NOT exceed 100 mrem (1 mSv) in a year, above background, from all radiation sources under control of the installation activity commander. Additionally, the dose in any unrestricted area from external radiation sources such as industrial X-rays SHALL NOT exceed 2 mrem (0.02 mSv) in any one hour.

6.9.5.2.5 Multiple Sources of Radiation. When any individual is likely to be exposed to radiation from more than one source simultaneously, or at different times, the protection associated with each source SHALL be increased so the total dose received by any one person from all sources SHALL NOT exceed applicable exposure limits. Additionally, the total effective dose equivalent (TEDE) limits, the sum of external and internal radiation exposure, requires special consideration be given to ensure the combination of internal and external exposure does not exceed limits.

6.9.5.2.6 Medical, Dental Diagnostic, or Therapeutic, and Natural Occurring Radiation.

CAUTION

Occupationally exposed personnel SHALL NOT wear their dosimetry devices while undergoing medical or dental X-ray procedures.

Radiation exposures resulting from necessary medical, dental, diagnostic, or therapeutic radiation procedures SHALL NOT be included in the determination of the radiation exposure status of the individual concerned. Similarly, exposures resulting from naturally occurring sources or from sources in consumer products, SHALL NOT be included in determining an individual's dose.

6.9.5.3 Personnel Monitoring Devices. TLDs are the primary dosimetry device and have generally replaced film badges as the legal record of radiation exposure in the Army. For more general information on TLDs see paragraph 6.3.10.2.1.

6.9.5.3.1 The Control Dosimeter (TLD). To accurately measure personnel dose, each radiography area will have at least one dosimeter designated as a "Control Dosimeter" (TLD/Film Badge). It is used to measure radiation exposure received by personnel monitoring devices (primarily from naturally occurring background radiation) while badges are in storage and transit.

a. The control dosimeter SHALL be stored in the same area as the personnel TLD, away from sources of radiation in a temperature and humidity controlled area. The control dosimeters SHALL NOT be removed from this area.

b. The control dosimeter SHALL NOT be worn by any individual.

6.9.5.3.2 Dosimetry (TLD). DA (and DLA) activities, including reserve forces, are required to use the Army dosimetry service provided by the US Army Dosimetry Center (ADC), TMDE Activity: AMSAM-TMD-SD.

Commander
US Army Aviation Missile Command
ATTN: AMSAM-TMD-SD (ADC) / Bldg. 5417
Redstone Arsenal, AL 35898-5000
Commercial: (256) 876-1858
E-mail: reds.adc@conus.army.mil

Organizations initiating industrial radiography operations SHOULD contact ADC in advance to assure receipt of dosimeters prior to the date on which such operations are scheduled to commence.

6.9.5.4 Personnel Radiation Monitoring Requirements.

6.9.5.4.1 Criteria. A monthly wearing period SHALL be implemented for thermoluminescent dosimeters (TLD) issued to minors and to pregnant women. Criteria requiring individual dosimetry are defined in: Title 10, Code of Federal Regulation, Parts 20 and 34; DA PAM 385-24 and the supporting DA Pamphlet. Use of personnel monitoring devices is mandatory for

each individual who MAY be exposed to ionizing radiation during the normal course of their duties or occupation according to the following criteria:

a. Occupationally exposed adults who may reasonably be expected to receive an annual dose in excess of 500 mrem (5 mSv).

b. Occupationally exposed adults entering any high or very high radiation area (regardless of the anticipated magnitude of exposure).

c. TLDs are the primary dosimetry device and have generally replaced film badges as the legal record of radiation exposure in the Army. For more detailed information regarding TLDs see paragraph 6.3.10.2.1.

d. Declared pregnant women who may be expected to receive a radiation dose exceeding 50 mrem (0.5 mSv) to the whole body/fetus for the entire period of pregnancy.

e. All minors who may reasonably be expected to receive an annual radiation dose in excess of 50 mrem (0.5 mSv) total effective dose equivalent (TEDE) to the whole body.

f. Other individuals as necessary for the effective management of the ALARA program, such as radiation safety monitors supporting unshielded radiography operations who do not otherwise require dosimetry devices, will be provided with dosimetry devices to include TLDs if their radiation dose would reasonably be expected to exceed the general public exposure limit of 100 mrem (1 mSv) TEDE per year or 2 mrem in one hour, above background.

g. Individuals not meeting any of the criteria contained herein SHOULD NOT be enrolled in, or be needlessly continued in the dosimetry program except on a case-by-case basis. If in doubt, RSOs SHOULD enroll individuals in the dosimetry program for a limited duration, and base continued use of dosimetry on actual exposures received.

6.9.5.4.2 Wearing of Whole-Body Dosimeters. TLD badges, used to provide a permanent record of the cumulative exposure to the whole body, SHALL be worn on the trunk (below the shoulders and above the hips) outside of clothing, on the portion or area of the body nearest the radiation source. The dosimeter window SHALL face out from the body.

6.9.5.4.3 Wearing Additional Dosimeters. If radiation exposure to the eyes, extremities, or skin is likely to be significantly different from whole body exposure, additional TLDs (collar, wrist, ring, etc.) SHALL be worn to document the actual exposure received by these areas. (Note: If eye protection providing at least 700 milligram per square centimeter thickness is used, the Post RSO SHALL annotate this fact on the dosimetry issue listing beside the individual's name so the correct eye exposure can be noted.)

6.9.5.4.4 Storage of Monitoring Devices. The RSO must approve all dosimeter storage locations. Each storage location must:

a. Be close to the area in which the occupationally-exposed individual works, yet outside of the areas where the radiation sources or devices are actually used or located.

b. Be adequately shielded from ionizing radiation.

c. Contain a control dosimeter.

6.9.5.4.5 Recording Readings of Direct Reading Dosimeters. Direct reading dosimeters SHALL be read and doses recorded daily in the utilization log. Record of theses exposures SHALL be maintained for 3 years after the record is made.

6.9.5.5 Dose Reporting and Recording Procedures.

6.9.5.5.1 Dose Record Custodian. Commanders SHALL designate in writing an individual to serve as the dose record custodian to be responsible for preparing and maintaining the records of occupational exposure to ionizing radiation. This individual MAY be the medical/health records custodian, RSO, or another individual who prepares the dosimetry report and controls dosimeter issuance and recovery. The Dose Record Custodian SHALL annotate in the "NRC" column of the dosimetry listing the number (found at the bottom of the dosimetry listing) which corresponds to the activity being performed (e.g., activities under a given NRC License number, LORAD LPX160, etc.). This is to ensure dose associated with a particular activity can be tracked for ALARA purposes.

6.9.5.5.2 Automated Dosimetry Record (ADR). Completed forms will be maintained on file for a minimum of one year from the date of last entry. It provides a complete occupational dose history for each occupationally exposed individual (upon written request from the RSO), calendar year-to-date updates of radiation exposures (on a quarterly basis), and includes dose records of whole-body and skin of the whole-body, head and neck, hands and forearms, feet and ankles, and lens of the eye, as applicable. The RSO verifies all ADR related information is contained in the ADR, takes action to correct errors, signs, and dates the ADR to certify the information as the occupationally-exposed individual's official dose record. The RSO also reviews and certifies each of the ADC updates and adds them to each individual's dosimetry record. (Updates for previous quarters during that calendar year need not be retained.)

6.9.5.5.3 Personnel Termination. Period and employment termination dose reports will be provided to occupationally exposed individuals in accordance with DA PAM 385-24.

6.9.5.6 Emergency Situations and Suspected Exposures Above Limits.

6.9.5.6.1 Emergency Situations.

a. In an emergency it may be necessary for individuals such as fire fighters or occupationally-exposed individuals to exceed radiation dose limits. In such a situation, the probable risk of high radiation exposure to the rescuer must be weighed against the expected benefits. Responders and incident commanders should understand the risks associated with radiation. Nothing in this chapter will be construed as limiting any immediate actions necessary to protect health and safety.

b. Table 6-29 provides emergency exposure dose limits for activities where exposures below 5 rems cannot be maintained.

Table 6-29. Emergency Exposure Dose Limits

Total Effective Dose Equivalent (TEDE) Guidelines	Activity	Conditions
5 rems	All occupational exposures	All reasonably achievable actions have been taken to minimize dose.
10 rems*	Protecting valuable property necessary for public welfare (e.g., a power plant).	Exceeding 5 rems unavoidable and all appropriate actions taken to reduce dose. Monitoring available to project or measure dose.
25 rems**	Lifesaving or protection of large populations.	Exceeding 5 rems unavoidable and all appropriate actions taken to reduce dose. Monitoring available to project or measure dose.
* For potential doses >10 rems, special medical monitoring programs should be employed, and exposure should be tracked in terms of the unit of absorbed dose (rad) rather than TEDE (rem).		
** In the case of a very large incident such as an improvised nuclear devise (IND), incident commanders may need to consider raising the property and lifesaving response worker guidelines in order to prevent further loss of life and massive spread of destruction.		

6.9.5.6.2 Actions for Emergency Situations and Suspected Exposures Above Limits. If the RSO cannot be notified, contact the Command Radiation Control Officer and the US Army Dosimetry Center (ADC) immediately by telephone, and promptly send the TLD badge(s) of all affected individuals, together with the appropriate control badge, by the most expeditious means to:

Commander
US Army Dosimetry Center ATTN:
AMSAM-TMD-SD (ADC)/ Bldg. 5417
Redstone Arsenal, AL 35898-5000
Commercial: (256) 876-1858
E-mail: reds.adc@conus.army.mil

NOTE

TLDs suspected of having received a potential overexposure SHALL be annotated as such, in writing, when they are shipped to the ADC for processing.

If an exposure above occupational limits is suspected, an emergency situation SHALL be considered to exist. The following actions SHALL be taken: (Consult 10 CFR 20, AR 385-40, DA PAM 385-24 and applicable supplements):

a. Immediately cease all radiography operations and report the incident to the Unit Commander.

b. Obtain the name, social security number, and organization of all personnel suspected of overexposure.

c. Notify the Post RSO of the suspected overexposure. Prepare to turn in the affected individual's TLD badge and the control badge for immediate processing, as directed. The occupational health physician in consultation with the RSO, will determine the need for medical treatment.

d. Read and record direct reading dosimeters.

e. Determine and record exact position and duration of exposure.

f. Update the Industrial Utilization Log as needed. Make sure the detailed sketch of the area includes the positions of personnel suspected of being overexposed. Record all other pertinent data about the incident.

g. Obtain a signed statement from the exposed individual(s) of action resulting in (or contributing to) the exposure.

h. After completion of the above phase of the investigation and in the case of non-monitored personnel being exposed, the following procedure can be used by the RSO or radiographers to quantify personnel exposure:

(1) Re-establish the exact position(s) of all objects at the time of the accident.

(2) Place suitable dosimetry devices at the position of the exposed individuals.

WARNING

Survey meters SHALL NOT be used, unless they have an integrate mode, or remote cameras are available to observe the instruments, since personnel using them will be unnecessarily exposed to radiation.

(3) Expose the dosimeters, operating the gamma ray or X-ray apparatus at the same technique as occurred during the incident, with the time of the exposure equal to the time personnel indicated they were present in the area or enclosure.

NOTE

If personnel were moving within the enclosure during the accident exposure, the dosimeters SHALL be placed at the position closest to the X-ray apparatus and at various points of his travel.

i. Upon return receipt of TLD results confirming personnel overexposures (or after validation of exposure dose to non-monitored personnel), the RSO SHALL complete accident investigations as specified in the paragraph below and report the accident pursuant to 10 CFR 20, AR 385-40 and DA PAM 385-24, as applicable.

j. Assure a new control badge is obtained and designated as a replacement for the control badge submitted for analysis.

6.9.5.6.3 External Potential Overexposure Criteria and Investigations. Upon the detection of a potential overexposure, the following investigations SHALL be made (DA PAM 40-18):

a. The US Army Dosimetry Center (ADC) SHALL promptly report to the RSO any dosimeter that exceeds the applicable Level II values found in Table 6-30. ADC also reports the results from dosimeters which indicate exposure exceeding criteria found in Table 6-31 to the RSO, to the Office of the Surgeon General, and to Head Army Materiel Command.

Table 6-30. Investigational Levels (Extract of Table 2-1, DA PAM 40-18*)

Quarterly Monitoring (mrem)		
	Level I	Level II
Whole body	125	375
Lens of the eye	375	1125
Other*	1250	3750
* DA PAM 40-18 is the companion DA pamphlet to DA PAM 385-24		

Table 6-31. Dosimeter Results Require Notification of OTSG (Extract of Table 4-1, DA PAM 40-18)

	Quarterly Monitoring (mrem)	Monthly Monitoring (mrem)
Whole body	1250	400
Lens of eye	3750	1250
*Other	12500	4150
* As used above, "Other" includes doses to the skin, or to any extremity, or any individual organ or tissue, other than the lens of the eye.		

b. For dosimeters used for industrial X-ray operations which were potentially overexposed at a rate exceeding limits in Table 6-30, the RSO SHALL:

(1) Conduct an investigation.

(2) Determine the cause, time frame, and circumstances surrounding the apparent potential overexposure.

(3) Take action or recommend to the commander corrective actions to prevent recurrence.

(4) Determine whether or not the dosimeter was actually worn by the occupationally exposed individuals during the dosimeter wear period.

(5) Report the overexposure in accordance with 10 CFR 20 and AR 385-40 (as applicable) if it is determined the badge was actually worn.

(6) Fully document the investigation and maintain investigation records as a permanent file per AR 25-400-2. Copies of the final investigation report including any to the individual also are provided to the individual concerned and to the individual's medical records custodian for inclusion in the individual's health or medical records. The written investigation report SHALL contain:

(a) A copy of the affected occupationally exposed individual's ADR covering the previous 12 months, if available.

(b) Results of any bioassay and medical examinations.

(c) Statements from supervisors or other knowledgeable personnel.

(d) A statement from the affected occupationally exposed individual stating, "To the best of my knowledge and belief I (did) (did not) receive this dose because_____."

(e) Procedures describing corrective actions.

(7) Review the ALARA program to reduce the likelihood of recurrence and minimize future radiation doses.

(8) Remove overexposed individuals from duties that could lead to additional radiation exposures pending completion of the overdose investigation.

(9) Refer any occupationally exposed individual who sustains an actual overexposure to the supporting occupational health physician. (The occupational health physician in consultation with the RSO will determine the appropriate medical examinations (if any) and plan appropriate medical care.)

6.9.5.6.4 Administrative Assessment of Dose. If a dosimeter is lost, damaged, or if the occupationally exposed individual's TEDE or CEDE cannot otherwise be determined, the Post RSO SHALL determine and assign an administrative dose pursuant to DA PAM 385-24, paragraph 4-13 and report the assigned dose to US Army Dosimetry Center for inclusion in the individual's permanent dosimetry file.

6.9.5.7 Radiation Surveys.

6.9.5.7.1 Definition. As used in this section, radiation protection survey means an evaluation of potential radiation hazards associated with the use of industrial X-and gamma ray equipment, under specified conditions, when used in protective, enclosed and/or unshielded locations. When appropriate, such evaluation includes inspection of equipment, examination of its location with reference to controlled and uncontrolled areas in the immediate environment, and measurements of exposure levels.

6.9.5.7.2 Shielded and Protective Installations. A radiation protection survey of all new shielded and protective X-ray installations, or new equipment in existing installations, SHALL be made by a fully qualified Health Physicist, Bioenvironmental Engineer, Nuclear Medicine Science Officer, or qualified Radiological Health Technician before the installation is placed into routine operation. The installation SHALL be inspected to verify adequacy of shielding, radiation protective devices and operational procedures.

6.9.5.7.2.1 Consultant Assistance. Consultant services of qualified health physicists can be obtained through command channels: from AMC Headquarters or from those organizations listed in paragraph 6.9.2.1, step m.

6.9.5.7.2.2 Local RSO Involvement. An assessment of shielded installations SHALL be made by, or under the direction of the local Post RSO initially before use. Assessments shall also be used before changes are made in shielding, operation, workload, equipment ratings or occupancy of adjacent areas when these changes, in the opinion of the RSO, can adversely affect radiation protection. If supplementary shielding is installed as a result of the radiation protection survey or re-evaluation, another survey SHALL be made to confirm the adequacy of the shielding after the modification.

6.9.5.7.2.3 Survey Methodology. When surveying shielded installations, the radiation exposure measurements SHALL be made in all adjacent areas accessible to personnel. The measurements SHALL be made under facility design conditions of operation that will result in the greatest exposure at the point of interest. X-ray apparatus SHALL be operated at the

maximum kilovoltage specified in the design criteria for the facility and at its maximum milliamperage for continuous operation at that voltage. High energy equipment (e.g., linear accelerators, betatrons, etc.) SHOULD be operated at maximum output.

6.9.5.7.2.4 Survey Conditions. In evaluating the results of the survey, consideration SHALL be given to actual operating conditions, including workload, use factor, occupancy factor, and attenuation of the useful beam provided by objects permanently in the path of the useful beam.

6.9.5.7.2.5 Compliance in Uncontrolled Areas. Whenever, in the opinion of the RSO or the radiographer, there is a reasonable probability a person in an uncontrolled area, adjacent to any type of radiation installation, may receive more than 2 mrem (0.02 mSv) in any one hour, or 100 mrem (1 mSv) in any calendar year, above background, then one or more of the following courses of action (whichever may be appropriate) SHALL be taken to ensure no person will receive exposure in excess of the basic radiation protection standard:

a. Use personnel or area monitoring devices to estimate the exposure received by occupants of the area, applying appropriate occupancy factors for each assessed location.

b. Add supplementary shielding to the protective barriers to ensure conformity with protective barrier recommendations contained in this publication.

c. Restrict use of the equipment (workload (on-time), kVp, or use factor).

d. Restrict occupancy of the area.

6.9.5.7.2.6 Identification of Radiation Hazards. Radiation hazards found in the course of a survey of any type installation SHALL be eliminated before the installation is used routinely. If the design and/or approved use of a shielded installation depend upon restrictions on the use factor of any primary barrier, it must be verified these restrictions are actually observed.

6.9.5.7.2.7 Inspection of Safety and Warning Devices.

WARNING

All interlock, "ON/OFF" beam control mechanisms, safety and warning devices, remote monitoring systems, etc., SHALL be inspected for proper operation PRIOR to initial operation, on each shift, when X-ray equipment will be used. Interlocks SHALL be subjected to detailed operational testing at intervals not to exceed six-months. A log initialed by the person making these inspections SHALL be maintained with the utilization log. Any malfunctioning devices SHALL be appropriately serviced prior to use and re-inspected to verify proper operation.

6.9.5.7.2.8 Unshielded Installation. Upon initial use, or use with new equipment, a detailed radiation protection survey of all unshielded installations SHALL be conducted by a fully qualified Health Physicist, Bioenvironmental Engineer, Nuclear Medicine Science Officer or qualified radiological health technician. Unshielded installations SHALL be actively surveyed by radiographers during each subsequent operation. Initial surveys SHALL include radiation exposure measurements to establish, or verify safe operating conditions as established by the applicable standard operating procedures. Equipment may be moved to another location for use if the post movement survey is performed by a qualified RSO.

6.9.5.7.2.9 Digital (Pulsed X-ray). For designation of unshielded areas where digital (pulsed X-ray) operations will be performed, radiation survey measurements are not required. The RSO or their representative SHALL evaluate each area to ensure that the restricted area is set up IAW paragraph 6.9.8.3.5.3. Additionally, all workers working in close proximity to digital X-ray operation SHALL be briefed on safety procedures and SHALL NOT enter the established restricted area.

6.9.5.7.3 Report of Radiation Protection Survey. Existing installations SHOULD NOT be assumed to conform to the provisions of this publication unless a valid radiation protection survey has been made by a qualified expert and a report has been placed on file at the installation.

6.9.5.7.4 Distribution and Retention of Survey Reports.

6.9.5.7.4.1 Survey Report Distribution. The written survey report of new or modified fixed radiography facilities SHALL be forwarded by the individual conduction the survey, through command channels to the owning organization with an information copy to the address below. A statement of corrective action(s) taken by the owning organization, if required, SHOULD be submitted to the appropriate Safety Office with information copy to:

Commander
US Army Aviation and Missile Command
AMSAM-SFO-R
5300 Sparkman Center Redstone Arsenal,
AL 35898-5000

Survey reports SHALL include recommendations for any corrective measures and SHOULD indicate if a further survey is necessary after corrections have been made.

6.9.5.7.4.2 Report Retention Requirements. Survey reports for fixed radiography facilities SHALL be retained by the Radiation Safety Officer and the organization performing industrial radiography (together with a record of corrective actions taken to address deficiencies) until such reports are superseded or radiography operations are permanently discontinued. All records of surveys performed (including those performed by radiographers and RSOs) SHALL be maintained for a minimum period of 5 years and then transferred to ARMIS.

6.9.5.7.5 Survey Report Contents.

a. Identification of the radiation source(s) and location of each by suitable means, e.g., serial number, room number, and building number or name.

b. The radiation output (kVp/mA) of the radiographic device. (The radiation output of the device will be the level specified by the manufacturer or obtained from remote survey readings. Unnecessary radiation exposure SHALL NOT be incurred to obtain such information.)

(1) X-ray source - in roentgens per minute (R/min), at one-meter, at maximum kVp and mA, (under shielding conditions indicative of normal operation). The potential and current at which the X-ray tube was operated during will be specified if less than the system operating limits.

(2) Gamma-ray source - in roentgens per minute (R/min) at one meter or specific activity remaining (curies or Becquerel) and calibration date.

c. Identification of the radiation survey instruments used, including serial number and date calibrated.

d. The location of the source and the orientation of the useful beam in relation to each exposure measurement.

e. Exposure rates in all adjacent areas accessible to personnel. The location of exposure rate measurements SHALL be in accordance with applicable criteria and SHALL be suitably identified by drawings when appropriate.

f. An assessment of whether the measured exposure rates will result in uncontrolled areas having a total exposure of greater than 2 mrem (0.02 mSv) in any one hour, or greater than 100 mrem (1mSv) in a year above background using the expected workloads, use factors and occupancy factors for the facility. The occupancy factor SHALL NOT be used to determine compliance with the 2 mrem (0.02 mSv) in any one hour limit.

g. A description of the existing mechanical and electrical limiting devices and safety devices that restrict the orientation of the useful beam and position of the source or otherwise support radiation protection efforts.

h. A statement indicating the appropriate classification of the installation (see paragraph 6.9.7) and the radiological design criteria for which it was designed, if available.

i. A statement of what controls are required if exposures are estimated to exceed 100 mR in a year or 2 mR in any one hour in uncontrolled areas. Engineering controls (e.g., additional shielding, physical barriers, etc.) SHALL always take precedence over administrative controls (e.g., restrictions on workload).

j. Identification of the individual conducting the survey, to include parent organization (plus the MOS or GS series for Army), and the date the survey was accomplished.

k. A statement of facility compliance/non-compliance with the following directives.

(1) If an installation does not comply with this publication, it SHALL be stated what action must be taken to ensure compliance.

(2) If a resurvey is required, it SHALL be so stated. The time frame as to when the resurvey is required, and whether or not operations are permitted prior to the resurvey SHALL be included.

6.9.5.7.6 Annual Radiation Assessment. A radiation assessment SHALL be made by the Post RSO or his/her representative, as an integral part of the annual quality assurance audit of the Radiation Protection Program. Assessments SHALL verify the adequacy of operating procedures, the presence and proper use of radiation warning signs and signals, and other necessary equipment. Annual ALARA training and assessment of worker dose to radiation SHALL also be verified and conducted if necessary. A formal report shall be generated to document the assessment findings and revalidate operating procedures and initial survey results and restrictions.

6.9.5.7.7 NDI Radiography Inspections. The radiographer-in-charge SHALL ensure a comprehensive radiation protection check is performed each time an X-ray inspection is performed. All radiographers SHALL ensure each exposure is adequately controlled IAW Post RSO survey and assessment parameters. Personnel SHALL check radiation levels prior to re-entry into a radiation area to ensure the radiation source has terminated.

6.9.5.7.7.1 Measuring Exposure Rates: Survey Meters (Ionization Chamber). For specific information on the operating principles, characteristics, and recommended survey meters for use, see paragraph 6.3.10.3.

6.9.5.7.7.2 Recommended Instruments for Exposure Measurements. Several instruments are suitable for measuring exposure rates resulting from NDI operations.

CAUTION

- Geiger-Mueller (GM) tube type instruments, such as the AN/PDR-27, AN/PDR-77, ADM-300, and AN/VDR-2, SHALL NOT be used during X-ray operations or X-ray radiation protection surveys. The response of GM-type instruments to the relatively low effective energies typical of X-ray operations is extremely variable. This extreme variability coupled with inadequate response to low X-ray energies MAY lead to serious personnel radiation overexposures. For example, at 32 keV the AN/PDR-27 measures only 1% of the true exposure rate.
- The VR-10 survey meter MAY reflect a false reading when in the presence of RFR environments. Interference MAY be the result of stray RFR energy being generated by the X-ray control panel components at exposure levels that do not present hazards to personnel. Caution SHALL be exercised using these meters at this location; however, the aforementioned does not preclude its use.

6.9.5.7.7.2.1 Common Instruments (Models 440, SM400, and VR-10 Survey Meters. Suitable instruments for industrial radiography include Victoreen model 451B, Victoreen model 451P, and Nuclear Research Corporation SM400A survey meters. Other survey instruments (Ion chambers) MAY also be considered providing that they have been approved by the AMCOM RSO.

6.9.5.7.7.3 Calibration of Radiation Surveys Instruments. Radiation survey meters used for X-ray radiography SHALL be calibrated as follows:

a. Radiation survey meter calibration SHALL be in accordance with TB 43-180. Calibration of radiation survey meters used with source radiography SHALL NOT exceed three-month intervals.

b. In addition, all meters, SHALL be calibrated after each instrument servicing. A record SHALL be maintained of the results of each instrument for 3 years after the date of calibration (10 CFR 34.24).

6.9.5.7.7.3.1 User Operational Check. The survey meter SHALL be checked by the user with a radiation check source prior to the first monitoring operation of the day.

6.9.5.7.7.3.2 Test Measurement and Diagnostic Equipment (TMDE) Calibration Requirements. Consult AR 750-43 (Army Test Measurement and Diagnostic Equipment Program), TB 750-25 (TMDE Calibration and Repair Support Program and TB 43-180 (Calibration and Repair Requirements for the Maintenance of Army Materiel) for detailed information on the calibration and repair programs. X-ray survey instrumentation can only be calibrated by the US Army TMDE Activity:

Transportation Office Central Receiving,
Building 8022
M/F: TMDE Building 5417
Redstone Arsenal, AL 35898
Commercial: (256) 876-0520/ DSN: 796-0520

6.9.5.7.7.4 Handling and Use of Radiation Survey Instruments.

6.9.5.7.7.4.1 Handling Survey Meters. Survey meters are delicate instruments; therefore, they SHALL be handled with care. Most survey instruments are not waterproof and shall be protected from wet weather conditions. If it rains when working outdoors, a clear plastic bag will have no appreciable effect on the radiation and will not hamper the operating of the control switches. If the components of the survey meter become wet, the instrument MAY have to be serviced and re-calibrated. When survey meters are transported in vehicles, they SHOULD be placed in the driver's compartment with adequate support and restraint to prevent damage during transit.

6.9.5.7.7.4.2 Guidelines for Use.

a. Whenever radiographic operations are performed, at least one calibrated and operable radiation survey instrument SHALL be available at shielded installations and at least two operable radiation survey instruments SHALL be available at unshielded installations. The instrument(s) SHALL be turned ON and available for immediate use by the radiographer during all radiographic operations. The instrument(s) SHALL have an adequate instrument response for the range of radiation energies encountered. When entering the area after deactivation of the radiation source, radiographers SHALL use a suitable, calibrated survey meter to assure the source has returned to its "off" position or that X-rays are no longer being produced.

b. Due to the response time of electrical components, survey meters will not instantly indicate the maximum exposure rate. Typically survey meters have a response time ranging from 2 to 15 seconds, with longer response times being required for lower dose rates. Therefore, prior to use, turn survey meters on for several minutes and allow them to stabilize. (The Victoreen 450B and 450P Models response time required to reach 90% of true value ranges from 3 to 8 seconds and from 3 to 5 seconds respectively.) Thus, in order to accurately measure the actual dose rate present, the operator must hold the survey meter in a set position for a period of time longer than the specified response time. Survey meter response times are published in the instrument instruction manual.

6.9.5.7.7.4.3 Survey Instruments Battery Check. If a battery indicator is located on the survey meter, it SHALL be checked each time the instrument is turned on. Some survey meters do not have a battery indicator. However, if the instrument can be zeroed with a zero control, sufficient battery power is available.

NOTE

The zero may constantly shift on some survey meters, so personnel using these meters SHALL continually recheck the zero control and adjust the meter as necessary.

6.9.6 Industrial Radiographic Operations.

6.9.6.1 System Types. There are two primary types of industrial radiographic systems; a sealed gamma-emitting radioactive source, typically referred to as a gamma camera, and machine-generated X-ray devices. Army radiographic operations primarily use machine generated X-ray systems. No gamma-emitting sources are currently used or are in the Army inventory.

6.9.6.1.1 Sealed Gamma Ray Sources.

CAUTION

Sealed sources used in radiography usually contain multi-curie quantities of gamma-emitting radioactive material and are extremely hazardous if not used properly. Therefore, each radiographer and radiographer's assistant must meet minimum training and experience requirements. A thorough understanding of the hazards and proper procedures for safe handling and use of radiography sources is a fundamental requirement for any individual who is to assume the duties and responsibilities of a radiographer.

6.9.6.1.2 Use of Sealed Gamma Ray Sources.

a. Activities SHALL NOT procure or use gamma sources (by-product material) until formally licensed to do so by the U.S. Nuclear Regulatory Commission (NRC). Application for NRC licenses is made by the RSO in accordance with DA PAM 385-24 through Command channels.

b. In cases where a contractor requests approval to perform X-ray inspections or gamma radiography (under the contractor's NRC or agreement state license) on federal property, the contractor WILL submit NRC Form 241 to Post RSO and the RSO will verify the validity of applicable licenses and initiate action pursuant to DA PAM 385-24 and 32 CFR 655.10 to obtain and/or issue a DA Radiation Permit. (RSOs SHOULD also ensure reciprocity notification has been provided to the applicable NRC Regional Office if the contractor is an agreement state licensee.) Although responsibility for safe use of sealed sources remains with the contractor pursuant to the contractor's license, RSOs SHALL review operating procedures to verify compliance with applicable regulations and to assure that Army personnel and property are protected.

6.9.7 Industrial Radiographic Installation Classifications.

6.9.7.1 NDI Installation Classifications. The Army classifies three types of installations: protective, enclosed, and unshielded. This ensures certain minimum standards of protection without needless expenditures.

6.9.7.1.1 Protective Installation.

a. The allowable usage exposure level for personnel on the dosimetry program, limits exposures to the lesser of 0.5 mrem (0.005 mSv) in any one hour or 2 mrem (0.02 mSv) per week (when corrected for workload, utilization, and type of occupancy) for this class of installation necessitates a higher degree of inherent shielding. The limit of 0.1 mrem (0.001 mSv) in one hour ensures with reasonable probability that under practical conditions of occupancy and use, the dose received by individuals outside the enclosure will not exceed the annual limit of 100 mrem (1 mSv) per year for members of the general public. For radiation sources of lower energies, and for smaller enclosures such as cabinets, the initial extra cost of the increased shielding is usually insignificant compared with the operational advantage.

b. At higher energies, as in the megavolt region with high workloads, the required additional shielding will usually make the use of this class extremely expensive compared with the enclosed installation.

6.9.7.1.2 Enclosed Installation. This installation provides fixed shielding for low use and low radiation levels. ("Protective" radiographic facilities generally will be used within the Army rather than "Enclosed" facilities.) This class usually offers the greatest advantage for fixed installations with low use and low occupancy factors. This is particularly true for high-energy sources where the reduction in shielding may result in significant savings. The shielding requirements are

considerably lower than for the protective installations, as much as 4.3 half-value layers (HVL) less; yet, the inherent protection is such that the possibility of significant overexposure is remote. With proper supervision, this class of installation offers a degree of protection similar to the protective installation.

6.9.7.1.3 Unshielded Installation. Applies where fixed shielding cannot be used (e.g., flight line, open hangars, make-shift buildings, etc.). This class SHALL NOT be selected unless operational requirements prevent the use of either of the other classes. For radiography, its use SHOULD be limited mainly to mobile and portable equipment where fixed shielding cannot be used. Fluoroscopy SHALL be done only by remote observation, such as by closed circuit television.

a. The protection of personnel and public depends almost entirely on strict adherence to safe operating procedures. With this adherence, unshielded installations may provide a degree of protection similar to the other classes.

b. The lack of inherent shielding necessarily increases the importance of an effective ALARA program. Additionally, lack of interlock and engineered access to high radiation areas increases the importance of unauthorized use of devices.

6.9.7.2 Requirements for Protective Facilities. An installation SHALL be classified as "protective" when it conforms to all of the following mandatory requirements:

NOTE

Each of the following SHALL be provided (except where specifically noted) without regard to the size and/or configuration of the enclosure:

a. Shielding requirements will limit radiation exposure as identified (see paragraph 6.9.9.1 and paragraph 6.9.9.2). No person, either within the controlled area or in the environs of "Protective" installations SHALL receive radiation exposures exceeding the total effective dose equivalent limits for members of the public.

b. The radiation source and all objects to be exposed are within a permanent enclosure and no person is permitted to remain within during irradiation.

c. Each entrance used for personnel access to the enclosure/high-radiation area SHALL have both visible and audible warning signals. These signals include: warning signs, beacons, and audible alarms, the latter two are tied to and discussed under "interlock system."

(1) Warning Signs.

(a) IAW 10 CFR 20.1902, the interior of the exposure room SHALL be posted with "Caution, High Radiation Area" or "Danger, High Radiation Area" or "Grave Danger, Very High Radiation Area" signs so they are visible from any location. The interior of a cabinet installation SHALL be posted with an identical sign that SHALL be visible with the access door opening.

(b) The entrance to the exposure room, or cabinet type installations housing X-ray equipment SHALL be posted with radiation marking signs, either "Caution, Radiation Area," "Danger, High Radiation Area" or "Grave Danger, Very High Radiation Area," as applicable. In addition, gamma radiography sources and cabinet type installations containing a radioactive source SHALL have a "Caution, Radioactive Materials" sign attached to the outside and a label or sign "Caution, Produces X-rays when energized" (or equivalent) SHALL be affixed to the X-ray tube head.

(2) Interlock System. The visible and audible warning beacons/signals SHALL be tied to an interlock system. The interlock system SHALL be placed on each door to interrupt power to the control box/tube head, stopping the irradiation process when unauthorized access is attempted. A time delay/interlock MAY be locally fabricated or purchased in order to meet this requirement. All time delay interlock systems installed SHALL be compatible with all X-ray units commonly available. The following paragraphs list items which SHALL all be tied to the interlock system.

(a) Pre-start Switch. SHALL be located inside the enclosure so if irradiation is interrupted by opening a safety interlock, resumption of operation can only be accomplished after the pre-start switch has been reactivated.

This ensures a thorough search for personnel working within the enclosure is conducted prior to activation of the source. A pre-start switch SHALL NOT be required if:

1 The tube head is de-energized (or gamma shutter is closed) when an interlock is tripped.

2 The X-ray tube (or gamma shutter) cannot be re-energized by merely closing the interlock. To re-energize the X-ray tube, the entire time delay interlock system must be re-initiated at the X-ray machine control panel.

(b) Pre-exposure Audible Alarm. A pre-exposure audible alarm SHALL be used within the enclosure and must be actuated at least 20 seconds before irradiation starts. Audible alarms SHALL cease when radiation is started, but the visible warning signal (see paragraph 6.9.7.2, step (c)) SHALL remain actuated during irradiation. The audible signal SHALL be of a frequency or capable of producing a sound pressure level so it can be heard over background noise that may be present. Audible alarms are not required if the enclosure is so small it cannot be entered by an individual. An example of such an enclosure is a cabinet X-ray system that has a small opening into which the part to be radiographed is placed, but into which an individual could not walk or even crawl without difficulty.

(c) Warning Beacons. Rotating or flashing strobe-type visible warning beacons SHALL be used at all entrances to the enclosure. These must be actuated at least 20 seconds before irradiation starts. These beacons SHALL be located so they are visible to an individual entering or already inside of the facility and will be operational when X-rays are being produced. An adequate sign SHALL be displayed near the lights to explain their function. Red warning beacons SHALL be located within the enclosure and red beacons SHALL be used outside all entrances to the enclosure. Low intensity, flashing, warning lights SHALL NOT be used unless special circumstances occur. The Post RSO SHALL be the only approval authority for these special circumstances.

(d) Entrance/Exit. A suitable means of exit SHALL be provided so any person who accidentally may be shut inside can leave the enclosure without delay. This door SHALL be tied to the interlock so if it is accidentally opened during exposure, it will automatically turn the exposure off. The shielded/protective facility shall not be used for excessive storage. All radiation warning signs and shut-off switches shall be at eye level (approx. 5 feet from ground) with no obstructions. Excessive clutter may interfere with accurate survey measurements and cause an unsafe condition should an emergency shut-off and egress from the facility become necessary.

(e) Emergency Shut-Off Switch. Emergency shut-off switch(s) SHALL be provided within the facility and labeled with a sign stating "EMERGENCY SHUTOFF" in white letters on a red background. Sufficient number of signs and switches SHALL be placed where they are visible and readily activated from any portion of the interior of the shielded/protective installation. The emergency shut-off switch shall not be obstructed. The area directly in front of and two feet on either side of the emergency shut-off shall remain clear at all times. An emergency shut-off switch SHALL NOT be required if the enclosure is so small that it cannot be entered by an individual. An example of such an enclosure is a cabinet X-ray system.

6.9.7.3 Requirements for Enclosed Installations. An installation SHALL be classified as “enclosed” when it conforms to all of the following mandatory requirements:

a. The source of radiation and all objects exposed thereto are within a permanent enclosure, within which no person is permitted to remain during irradiation.

b. Each entrance used for personnel access to the enclosure/high-radiation area SHALL have both visible and audible warning signals to warn of the presence of radiation. The visible signal SHALL be actuated by radiation whenever the source is exposed/in operation. The audible signal SHALL be actuated when an attempt is made to enter the enclosure while radiation is being produced (10 CFR 34.29(b)). In addition, reliable dual independent interlocks are desirable on each door to prevent access to the enclosure during irradiation. A single interlock system on each door to prevent access to the enclosure during irradiation is a mandatory requirement.

c. Each of the following SHALL be provided (except where specifically noted) without regard to the size and/or configuration of the enclosure.

NOTE

A time delay interlock MAY be locally fabricated in order to meet this requirement. The suggested design is optional and not mandatory since numerous design approaches can be used. The wiring harnesses are similar to the harnesses used with X-ray interlock assembly, NSN 6635-00-292-7637. All time delay interlock systems installed SHALL be compatible with all X-ray units commonly available.

(1) Pre-exposure audible alarms and rotating red visible warning signals within the enclosure that must be actuated at least 10 seconds before irradiation can be started. A sign SHALL be displayed near these devise to explain their function. Audible alarms will cease when radiation is started, but visible warning signal will continue throughout exposure.

(2) Suitable means of exit so any person who accidentally may be shut in can leave the enclosure without delay.

(3) An emergency shut-off switch SHALL be provided within the facility labeled by a sign "EMERGENCY SHUT-OFF" in white letters on a red background. Sufficient number of signs and switches SHALL be placed such that they are visible and readily activated from any portion of the interior of the enclosed installation. If only one emergency shut-off switch is provided, it SHOULD NOT be adjacent to a personnel exit door since the door itself can act as an emergency shut-off device. The switch SHOULD be located as far from the door as practical.

(4) Red, rotating, or flashing strobe-type visible warning beacons SHALL be used on the perimeter and positioned at the X-ray source (low-intensity flashing warning lights SHALL NOT be used). Rotating or flashing strobe-type warning lights SHALL be used; red inside the enclosure and red or yellow outside all entrances to the enclosure. These lights SHOULD be located at approximately eye level and SHALL be operational. An adequate sign SHALL be displayed near the lights to explain their function. If:

(a) The shielding provided by the roof is less than provided by the walls, or

(b) There is direct access from the roof into the exposure room, then one of the following SHALL be provided:

1 Low intensity, flashing warning lights SHALL NOT be used. A rotating or flashing strobe-type red or yellow light on the roof with an explanatory sign adjacent to it along with the appropriate radiation warning sign, or

2 An appropriate radiation warning sign and sign indicating "Restricted Area, Contact (name, extension) Before Entering," on all permanent accesses to the roof and on the roof itself so it will be visible to anyone attempting to climb onto the roof. Ideally, there will also be a rope barrier provided across the entryway.

(c) A pre-start switch located inside the enclosure such that if irradiation is interrupted by the opening of a safety interlock, resumption of operation can only be accomplished after the pre-start switch has been reactivated. A pre-start switch is not required provided that:

1 The tube head is de-energized (or gamma shutter is closed) when an interlock is tripped.

2 The X-ray tube CANNOT be re-energized by merely closing the interlock. To re-energize the X-ray tube, the entire time delay interlock system must be re-initiated at the X-ray machine control panel. (Comparable, the gamma shutter cannot be opened without proceeding through the standard system setup/initiation procedures.)

(d) The exposure at any accessible and occupied area one foot (30 cm) from the outside surface of the enclosure does not exceed 2 mrem (0.02 mSv) in any one hour and the exposure at any accessible and normally unoccupied area one foot from the outside surface of the enclosure does not exceed 20 mrem (0.2 mSv) in any one hour. (Access to normally unoccupied areas in which doses could exceed 2 mrem (0.02 mSv) in any one hour or result in exposures to members of the public exceeding 100 mrem (1 mSv) per year, above background, must be secured or continuously monitored to preclude personnel entry.)

1 For X-ray installations, these exposure limitations SHALL be met for any X-ray tube to be used in the enclosure and operated at any specified mA and kVp rating within the manufacturers published recommendations.

2 Beam limiting devices or filters SHALL NOT be used during these tests unless such devices and filters are permanently attached to the X-ray tube or gamma exposure device and the unit cannot be operated without their use. The radiation source and beam direction SHALL be positioned and oriented such that the highest exposure rate will be encountered in the area under test provided that such positioning and orientation will serve a practical purpose in normal usage.

(e) All enclosed installations SHALL display suitable Warning signs as given below:

1 IAW 10 CFR 20.1902, the interior of the exposure room SHALL be posted with sufficient "Danger, High Radiation Area" or "Grave Danger, Very High Radiation Area" signs as applicable and visible from any location in the room. The interior of a cabinet installation SHALL be posted with an identical sign which SHALL be visible with the access door open.

2 IAW 10 CFR 20.1902, the entrance to the exposure room and cabinet of cabinet type installations housing X-ray equipment SHALL be posted with radiation marking signs, either "Caution, Radiation Area," "Danger, High Radiation Area" or "Grave Danger, Very High Radiation Area," as applicable. In addition, gamma radiography sources and cabinet type installations containing a radioactive source SHALL: have a "Caution, Radioactive Materials" sign attached to the outside and a label or sign "Caution, Produces X-rays when energized") or equivalent) SHALL be affixed to the X-ray tube head.

3 The area accessible to personnel where radiation doses could exceed 5 mrem (0.05 mSv) in any one hour SHALL be posted with a “Caution, Radiation Area” sign. For purposes of ensuring no member of the public receives an exposure exceeding 100 mrem (1 mSv) in one year above background, the barrier to the area where the radiation dose could exceed 5 mrem(0.05 mSv) in any one hour SHOULD be posted at 2 mrem/hr (0.02 mSv/hr).

(f) No person, either within the controlled area or in the environs of the installation is exposed to more than the radiation protection standard applicable to members of the public unless exposure is approved in writing, in advance, by the Radiation Safety Officer.

Table 6-32. Radiation Area Definitions

Area	Definition
Radiation Area	An area where an individual located 30 centimeters from the any source of radiation could receive greater than 5 mrem (0.05 mSv) in one hour.
High Radiation Area	An area where an individual located 100 centimeters from any source of radiation could receive greater than 500 rads (5 Gy) in one hour.
Very High Radiation Area	An area where an individual located 100 centimeters from any source of radiation could receive greater than 500 rads (5 Gy) in one hour.

6.9.7.4 Unshielded Installations. An installation SHALL be classified as "unshielded" if due to operational requirements it cannot be provided with the inherent degree of protection specified for either Army “protective” or "enclosed" installations. Such installations include fenced or "roped-off" areas located either in the open, or inside buildings such as hangar bays. Unshielded installations SHALL conform to all of the following requirements:

NOTE

High Radiation Area boundaries SHALL be calculated only. Surveys SHALL NOT be performed unless such surveys can be accomplished (using devices such as those that integrate dose) without additional unnecessary exposure to personnel.

a. A second perimeter delineating a "Radiation Area" SHALL be calculated, posted with sufficient "Caution, Radiation Area" signs so as to be conspicuous from any direction of approach, and radiation levels verified by radiation surveys. Such radiation surveys SHALL be documented in operating logs and SHALL include a minimum of two readings for each side of the radiation boundary. (A "Radiation Area" is defined as any area accessible to individuals in which ionizing radiation dose rate levels could result in an individual receiving a dose in excess of 5 mrem (0.05 mSv) in one hour at 30 centimeters (one foot) from the radiation source or from any source that the radiation penetrates.)

b. Compliance with radiation dose limits applicable to the general public and to occasionally exposed individuals requires that access to areas in which radiation doses could exceed 2 mrem (0.02 mSv) in any one hour or 100 mrem (1 mSv) in a year, above background, SHALL be restricted. “Radiation Area” postings SHALL be extended out from the X-ray tube such as to encompass such areas, or alternative arrangements made to restrict access to this area.

c. If the beam orientation or technique factors change between exposures, the radiation area boundaries SHALL be re-established and the boundaries of radiation areas reverified.

d. Red rotating or flashing strobe-type visible warning beacons SHALL be used on the perimeter and positioned at the X-ray source (low-intensity flashing warning lights SHALL NOT be used). The beacon, positioned at the source SHALL be rotating/flashing only when the source is energized.

e. An X-ray interlock or gamma shutter, as applicable, SHALL be installed between the control unit and the rotating/flashing strobe-type X-ray (or gamma) "on" beacon. The interlock assembly enables electrical power to the "X-ray On" power circuits only after the rotating/flashing strobe-type "X-ray On" warning beacon is attached. X-/gamma radiography interlocks SHALL be inspected by radiographers each day prior to use of the X-ray equipment to verify proper operation. The interlock SHALL be tested every 6 months by verifying it does indeed de-energize the X-ray tube head when the exposure is complete, the circuit is tripped or it is manually shut off by the operator. For units using the PCAMS system, add the interlock check at 180 day intervals.

f. If the perimeter is of such a size or is so arranged that the operator cannot readily determine whether the radiation area is unoccupied, a sufficient number of radiographers and/or radiation safety monitors and/or safety monitor assistants SHALL be strategically located to provide adequate visual surveillance over the entire area. These personnel SHALL have in their possession an adequate and properly calibrated, operable survey meter. The requirement for additional monitors MAY not be necessary if: the radiographic procedures are to be accomplished in a fenced-in or locked area to which access is controlled by the radiographer. In addition, there SHALL NOT be less than one radiation safety monitor. (X-ray and gamma ray controls SHOULD be placed so all monitors, for the entire perimeter of the barrier, can be seen and heard by the radiographer-in-charge. If this is not possible, a hand held battery powered communication device of intrinsically safe design SHALL be utilized.)

g. The radiation source and equipment essential to the use of the source SHALL be made inaccessible to unauthorized use, tampering or removal while not in use. This SHALL be accomplished by such means as a locked enclosure.

h. Two qualified radiographers and as many radiation safety monitor assistants as needed SHOULD be used. If two qualified radiographers are not available, at least one qualified radiographer and as many radiation safety monitor assistants (see paragraph 6.9.2.5) as required to prevent radiation barrier penetration SHALL be present for radiographic operations. Training for radiation safety monitor assistants SHALL be conducted IAW (see 6.9.4.4). This applies to standard industrial X-ray

i. If the unshielded installation is in a remote area, and if entry into the enclosed area can be absolutely prevented during irradiation, the source and all objects exposed SHALL be within a conspicuously posted perimeter that limits the area in which the exposure can exceed 100 mR/hr (1 mSv/hr) in an hour provided:

(1) The 2 mR/hr (Radiation Area) boundary is posted with a sufficient number of "Caution, Radiation Area" signs so as to be conspicuous from any direction of approach.

(2) The boundary of the restricted area can be determined where applicable.

(3) All requirements of this document (including paragraph 6.9.7.6) can be met.

j. Personnel SHALL NOT be exposed to more than the dose limits prescribed in DA PAM 385-24 or paragraph 6.9.5.2 of the T.M.

k. When entering the area after deactivation of the radiation source, radiographers SHALL use a suitable calibrated survey meter to assure the source has returned to its "off" position or that X-rays are no longer being produced.

6.9.7.4.1 Unshielded (Pulsed X-ray). For details regarding pulsed operations, see paragraph 6.9.8.3.5.

6.9.7.5 New Facilities. New radiation facilities SHALL be constructed to meet the requirements of one of these classes of installations. The classes differ in the relative dependence on the "inherent shielding," "operating restrictions," and "supervision" necessary to secure the required degree of protection. In addition, each class has certain advantages and limitations. The above referenced paragraphs contain details of the respective installation classes.

6.9.7.6 High Radiation Areas. Each of the types of installations specified herein involves the creation of "High Radiation Areas." Access to all high radiation areas created by radiographic operations with sealed sources SHALL be controlled in accordance with 10 CFR 20.1601. 10 CFR 20.1601 also states controls WILL NOT prevent an individual from leaving a high radiation area. To ensure high levels of safety, these rules will also be applied to radiographic operations performed with X-ray sources. Requirements include one or more of the following features:

a. Control devices that, upon entry into the area, cause the level of radiation to be reduced (below that level at which an individual might receive a deep-dose equivalent of 100 mrem (1 mSv) in one hour at 30 centimeters from the source (or from any surface that the radiation penetrates).

b. Control devices that energize a conspicuous visible or audible alarm such that the individual entering the area, and the supervisor of the activity, are made aware of the entry.

c. Entries that are locked, except during periods when access to the areas is required, with positive control over each entry.

d. Continuous direct or electronic surveillance capable of preventing unauthorized entry.

6.9.7.7 Very High Radiation Areas. A "Very High Radiation Area" is an area in which radiation levels could be encountered at 500 rads (5 gray) per hour at one meter from a radiation source or from any surface that the radiation penetrates (10 CFR 20.1602). Additional measures SHALL be instituted to ensure that an individual is not able to gain unauthorized or inadvertent entry into a "Very High Radiation Area." The requirements of 10 CFR 20.11603 SHALL be implemented for all radiation sources, including X-ray machines, which create very high radiation areas.

6.9.8 Mandatory Operating Procedures.

6.9.8.1 Operating Procedures for Protected Installations. The following are mandatory operating procedures that SHALL be adhered to in "protective" installations:

a. No restrictions SHALL be imposed on the mode of operation (kVp, mA, workload, or adjacent operations) for protective installations.

b. A thorough search for personnel working within the enclosure SHALL be conducted prior to activating the source.

c. The installation SHALL be inspected by the radiographers each day the facility is to be used to verify the proper operation of audible and visible warning signals, interlock, delay switches, and other exercises that have a bearing on radiation protection. Interlocks SHALL be subject to detailed testing at intervals not to exceed six-months to assure that they function as designed. A utilization log, initialed by the individual making the inspection, SHALL be maintained.

d. Except when making daily verification of safety interlock operation and in emergencies, door interlocks SHALL NOT be used as a means of terminating the exposure. The exposure SHALL be terminated at the control panel.

e. When radiograph exposures have been completed, the safety switch key SHALL be removed from the control panel. The radiation-producing equipment and power safety-switch key SHALL be removed from the control panel. The radiation-producing equipment and power safety-switch key SHALL be placed in secure areas separate from one another. Only radiographers specifically authorized by the Commander SHALL have access to the storage areas.

f. When entering the exposure room after deactivation of the radiation source, radiographers SHALL use a calibrated survey meter to ensure the source has returned to its "off" position (X-rays are no longer being produced).

6.9.8.2 Enclosed Installation Operating Procedures. The following are mandatory operating instructions that SHALL be adhered to for enclosed installations.

a. Since the safe operation of an "enclosed" installation is based on the normal operating conditions specified in the applicable radiation protection survey report, the equipment SHALL be operated only within the indicated limits. A copy of the survey report SHALL be readily available during radiographic exposures.

b. When the operating conditions have changed so there is a probability the exposure of any person may be increased, a radiation protection resurvey or evaluation SHALL be conducted. When in doubt, a health physicist or nuclear medicine science officer SHALL be consulted.

c. Personnel access to area where radiography is in progress SHALL be limited to that which is absolutely required. All entries into the enclosure SHALL be monitored.

d. A thorough search for personnel working within the enclosure SHALL be conducted prior to activating the source.

e. The tube head, or gamma radiography source, as applicable, SHOULD be placed as close as possible to the center of the room. Whenever possible the beam SHOULD be directed toward the floor and a piece of 1/8 inch thick lead plate SHOULD be placed on the floor to interrupt the entire primary beam in order to reduce scatter radiation.

f. The installation SHALL be inspected by the radiographers each day the facility is to be used to verify the proper operation of audible alarms, red visible warning signals, interlocks, delay switches, and other devices that have a bearing on radiation protection. Interlocks SHALL be tested by verifying they do indeed de-energize the tube head when tripped. Interlocks will be subjected to detailed testing at a frequency not to exceed 6 months. A log, initialed by the individual making the inspection, SHALL be maintained.

g. A qualified radiographer SHALL be present at the console panel during all radiographic exposures and will be the only person authorized to operate radiography equipment. A calibrated survey instrument SHALL be available for immediate use by the radiographer during all radiographic operations.

h. Except when conducting daily verification of safety interlock operation and in emergencies, door interlocks SHALL NOT be used to terminate the exposure. The exposure SHALL be terminated at the control panel.

i. When radiographic exposures have been completed, the power safety-switch key SHALL be removed from the control panel. The radiation-producing equipment and power safety-switch key SHALL be placed in secure areas separate from one another. Only radiographers authorized by the Unit Commander SHALL have access to the storage area.

j. When entering the exposure room after inactivation of the radiation source, radiographers SHALL use a calibrated survey meter to ensure the source has returned to its "off" position (X-rays are no longer being produced).

6.9.8.3 Unshielded Operating Procedures. The following are minimum requirements that SHALL be adhered to when performing radiographic inspection operations in "unshielded" areas:

6.9.8.3.1 General. Industrial X-ray or sealed gamma-ray sources will be used in unshielded areas by only qualified radiographers and with written approval of the Radiation Safety Officer. (Devices generating “Very High Radiation” areas SHALL NOT be used in unshielded areas without prior written approval from the applicable Headquarters.)

6.9.8.3.2 Required Equipment. In addition to the radiation producing equipment, the following equipment SHALL be used at the site selected for radiographic purposes:

a. At least two serviceable, properly calibrated radiation survey meters authorized for use with X-ray or gamma radiography operations, as applicable. One instrument SHALL be placed near the operator’s console, and the other utilized for surveys of the perimeter as appropriate. Each radiation survey meter SHALL be checked for acceptable response to radiation using the provided check source prior to the first operation of the day or shift, and after suspected damage such as would occur if dropped.

b. TLDs are the primary dosimetry device and have generally replaced film badges as the legal record of radiation exposure in the Army. For more information see paragraph 6.3.10.2.1.

c. Radiation warning signs: sufficient quantity of each required type, e.g., "Caution, Radiation Area" and "Caution" or "Danger" "High Radiation Area."

d. For X-ray equipment, at least 75 feet of power cable and coolant hose; or as recommended by the equipment manufacturer.

e. A red rotating/flashing strobe-type beacon (low intensity, blinking warning lights SHALL NOT be used) and in some situations, as specified by the Post RSO, a radiation warning sign stating "X-ray ON" (or "SHUTTER OPEN" for gamma radiography), when the light is lit. The rotating/flashing strobe-type red beacon SHALL be as close to the radiation source as possible and still be visible from all angles of approach, and SHALL be connected to the control circuit in such a manner the light will be ON when the radiation source is activated. An "X-ray ON" light is typically used at entrance locations to an unshielded facility and is lit during irradiation.

f. For night radiographic operations, sufficient lighting equipment to illuminate the area.

g. Minimum of 500 feet (150 meters) of commercially available barrier material that states "CAUTION RADIATION AREA" (bright yellow background with magenta or black letters and radiation symbol) and self-supporting stands MAY be used to cordon off the affected area.

6.9.8.3.3 Establishment of Restricted Area. Radiographic operations in unshielded facilities require an initial evaluation of the exposure area to determine the bounds of the area to be restricted during exposure.

a. A restricted area means: "any area to which access is controlled by the individual in charge of radiation protection for the purpose of protection of individuals from exposure to radiation and radioactive materials." This implies a restricted area is one that requires control of access, occupancy, and working conditions for radiation protection purposes.

b. The dose limit in any unrestricted area from external radiation sources SHALL NOT exceed 2 mrem (0.02 mSv) in any one-hour. In addition, operations SHALL be conducted so radiation exposure to individual members of the public SHALL NOT exceed 100 mrem (1 mSv) in a year above background. It SHALL be noted the definition does not limit the radiation exposure to a particular rate (such as 4 mR/hr), but permits higher exposure rates PROVIDING that the total quantity of radiation in any unrestricted area during any one hour does not exceed 2 mrem (0.02 mSv) and during any calendar year considering occupancy factors, does not exceed 100 mrem (1 mSv) to any single individual. Occupancy factor SHOULD be considered for determining compliance with the annual limit.

c. Special consideration SHALL be given to ensure restricted areas are of sufficient size to preclude adverse impact on adjacent operations. When in doubt, ensure qualified experts are consulted prior to initiation of operations.

d. Summary data, comparing the measured exposure rate with the maximum allowable on-time (in minutes per hour) of the radiation source so the total dose in any one hour does not exceed 2 mrem is provided (see Table 6-33).

Table 6-33. Maximum Permissible Dose Rate versus Hourly Duty Cycle

Measured Exposure Rate (mrem/hr)	Total time X-ray is Operated During a One-Hour Period (minutes)
30	4
24	5
20	6
17	7
15	8
13	9
12	10
8	15
6	20
5	24
4	30
2	60

6.9.8.3.4 Operations.

a. Once the restricted area is identified, it SHALL be adequately posted to ensure against inadvertent entry. In some buildings, it may be feasible to lock appropriate doors or limit access to very large work areas as a simple means of radiation area control. In other locations it MAY be necessary to establish boundaries by roping off or barricading passageways at appropriate locations. In any event, sufficient control in the form of posting, use of safety monitors and use of access-limiting devices SHALL be in place to guarantee no individual can enter the area inadvertently.

b. In general, when radiographic operations are conducted without benefit of shielding it is often necessary to erect a rope barrier around X-ray tube head at a distance of 70 meters (230 feet) or more for vertical beam orientation. For exposures requiring near horizontal or horizontal beams, the barrier MAY have to be extended in the direction of the beam for more than a hundred meters to achieve exposure rates at the barrier less than or equal to the maximum limits. (Fixed or portable shielding SHOULD be used whenever practicable to reduce the size of area which must be controlled.) All entrances into the isolated area SHALL be secured and posted, and any uncontrolled area must not contain exposure rates that would allow personnel to receive in excess of 2 mrem (0.02 mSv) in any one hour. All positions around the barrier SHALL be in view of one of the radiographers or radiation monitors during exposures.

c. Place radiation warning signs along the barrier so at least one can be seen from any direction of approach.

d. Extend the power cable from the tube head to the controls so the operator is located as far as possible from the radiation source, usually at least 75 feet (23 meters). Place the controls so all monitors, or the entire perimeter of the barrier, can be seen by the radiographer. If this is not possible, either a consultant health physicist, or Nuclear Medicine Officer, or other qualified individual SHALL specify adequate means of communication during a survey of the unshielded operation. Adequate means of communications MAY include two-way radios, whistles, electronic/propellant-activated noise alarms or ultrasonic infrared intrusion barriers, but need not be limited to these methods.

e. Place the red, rotating/flashing strobe-type (X-ray warning) beacon, near the X-ray tube and connect to the X-ray interlock circuit.

f. Illuminate the area for night operation.

g. Ensure no one is inside, on top, or below the object being radiographed.

h. Prior to making an exposure, the area SHALL be surveyed by the radiographers to establish pattern of any radiation fields that could be present and to determine the adequacy of rope barrier placement.

i. Upon completion of the survey and modification of the barrier, if needed, put the film in place and proceed with the radiographic exposure.

j. If the barrier is penetrated by anyone during the exposure, the radiation source SHALL be immediately turned off, the individual detained, the area secured, and the incident reported to the radiography supervisor. Begin emergency procedures.

k. The radiographic apparatus SHALL NOT be left unattended when operating and unauthorized personnel SHALL NOT operate it. This equipment SHALL always be stored in a secure area. A key lock SHALL be installed on all radiographic unit consoles. While in storage or unattended by an authorized radiographer, the power safety-switch key SHALL be removed from the console and securely maintained separate from the apparatus. Only radiographers authorized by the Unit Commander SHALL have access to the industrial radiographic unit power safety-switch key storage areas.

CAUTION

The LORAD Class 3R laser pointer SHALL NOT be directed above the horizon near the flight line, as this may be dangerous to flight operations. The laser will have a warning affixed to it and it SHALL only be in the on position when aligning film and off at all other times. The laser will be treated as a dangerous tool and SHALL not be pointed at any individual.

l. In the case of multiple exposures in an open area in which the beam direction, intensity (kVp, mA) or attenuating materials are significantly altered, the barrier perimeter SHALL be re-established as necessary.

m. All information required on the utilization log SHALL be recorded by the radiographer in charge. The completed form will be permanently maintained on file for three years. If a suspected overexposure occurs, any other documents generated during the subsequent investigation SHALL be filed with the respective utilization log. When a log is completed, the radiography supervisor (lab chief) will sign the log. (If a suspected overexposure has occurred, see paragraph 6.9.5.6 for instructions.)

6.9.8.3.5 Unshielded (Pulsed X-ray) Operating Procedures. The following are minimum mandatory requirements that SHALL be adhered to when performing digital radiographic operations in "unshielded" areas. Requirements are based on the current pulsed X-ray systems used, approved operations and techniques, and a study completed by AFIOH/SDRH. If new pulsed X-ray systems are acquired with an X-ray tube head output greater than 3.5 mR/pulse at one foot from the tube head and/or a tube current rating greater than 0.5 mA, contact organizations located at paragraph 6.9.2.1, step j, for additional guidance.

6.9.8.3.5.1 General. Industrial X-ray operations involving pulsed x-rays will only be accomplished by qualified radiographers and with written approval of the Post RSO.

6.9.8.3.5.2 Required Pulsed X-ray Equipment. In addition to the radiation producing equipment, the following equipment SHALL be readily available for use at the site selected for radiographic purposes.

a. A minimum of one TLD badge for each radiographer involved in the radiography operations. If only pocket dosimeters (pocket chambers) are available, two dosimeters per radiographer are recommended.

NOTE

The electronic personal dosimeters (EPD), personal alarming dosimeter (PAD) and Digital Alarming Dosimeter (DAD) do not accurately measure radiation in short-pulsed (60 nanosecond) X-ray environments.

b. At least 75 feet of rope with sufficient supporting stands (recommended).

c. Radiation warning signs: sufficient quantity (minimum of least two) stating "Caution, Radiation Area."

d. For X-ray equipment, at least 12 feet X-ray tube head activation cord.

e. The tube head SHALL provide visual and audio indication of tube activation and require key activation.

f. For night radiographic operations, sufficient lighting equipment to illuminate the area.

g. A minimum of 75 feet of commercially available barrier material which states "CAUTION RADIATION AREA" (bright yellow background with magenta or black letters and radiation symbol) and self-supporting stands may be used to cordon off the affected area.

6.9.8.3.5.3 Establishment of Restricted Area for Pulsed X-ray. The radiation scatter and primary beam footprint for short- pulsed X-ray operations is minimal. Additionally, low energy pulsed X-ray scatter radiation is difficult to accurately measure. Therefore, restricted area requirements are defined below to ensure compliance with the general public exposure limits identified in paragraph 6.9.5.2.4. Assumptions used for this determination included a total workload of 30,000 images per year, 27 pulses per image and up to 40 images per hour. An occupancy factor of 0.5 was used for determining compliance with the yearly

a. For vertical image projections, a 16 foot radius around the tube head is required. Additionally, the primary beam SHALL be controlled to 28 feet. For the occasional horizontal image projections, a 16 foot area SHALL be controlled to the sides and back of the tube head. On the target end of the tube head a 28 foot area must be controlled. The unit has a radiation cone angle of approximately 40 degrees.

b. Trained NDI personnel SHALL always maintain a minimum distance of 12 feet from the tube head and stay out of the primary X-ray beam to ensure radiation dose is ALARA.

6.9.8.3.5.4 Pulsed X-ray Operations.

a. Once the restricted area is identified, it SHALL be adequately posted to assure against inadvertent entry. In some buildings, it MAY be prudent to lock appropriate doors, or limit access to work areas as a simple means of radiation area control. In other locations it MAY be necessary to establish boundaries by roping off or barricading passageways at appropriate locations. In any event, sufficient control in the form of posting, use of safety monitors and use of access limiting devices SHALL be in place to guarantee no individual can enter the area inadvertently.

b. All positions around the barrier SHALL be in view of at least one of the radiographers or radiation monitors during exposures.

c. Place radiation warning signs along the barrier so at least one can be seen from any direction of approach.

d. Place the controls so the entire perimeter of the barrier can be seen by the radiographer. If this is not possible, either a consultant health physicist or Nuclear Medicine Science Officer or other qualified individual SHALL specify adequate means of communication during a survey of the unshielded operation. Adequate means of communications MAY include two-way radios, whistles, electronic/propellant-activated noise alarms, or ultrasonic infrared intrusion barriers, but need not be limited to these methods.

e. Illuminate the area for night operation.

6.9.8.4 Utilization Log. The industrial radiography utilization log, AFTO Form 125 or equivalent, shall be completed for all protected, enclosed, unshielded inspections and suspected overexposures of personnel. A separate form is required for each type of part to be radiographed. The following information shall be recorded:

a. Facility Location: Identify building number, street address, and room number if applicable.

b. Organization: Enter maintenance organization radiographers are assigned.

c. Aircraft Tail number: Identify model number of aircraft that part or component is attached to or removed from.

d. Part/Component: Identify part nomenclature to be radiographed, similar part/components may be grouped as a series as long as the general x-ray beam orientation and kV and mA setting do not change.

e. Date: Enter date of inspection.

f. Supervisor: Enter the name and rank of radiographer-in-charge. A new entry is required if the supervisor changes.

g. Shift: Enter the duty shift of the operation. A new entry is required if the operation covers multiple shifts.

h. Number of exposures: Enter the number of exposures performed to complete a specific radiographic inspection. Multiple exposures are only authorized if the exposure series parameters do not change (e.g., wing inspections will have multiple exposures with the same beam direction, kV and mA).

i. kVp: Enter kVp used to radiograph the part/component.

j. mA: Enter mA used to radiograph the part/component.

k. Radiation Level: Enter highest recorded survey meter reading from predetermined points around the barrier. One monitor can observe meter readings from various locations. Refer to sketch drawing to determine where the readings will be observed and recorded. Each number on the radiation level block should correlate with a number in the sketch.

l. Sketch of Restricted Area: Prepare a detailed sketch in accordance with the Post RSO's survey and assessment determinations to identify the following:

(1) Aircraft/part orientation or position.

(2) Tube head location, position and beam direction.

(3) Control console position. (Shall also be radiographer-in-charge position and correlates with the number one position in the radiation level block.)

(4) Barrier position.

(5) Exposure rates in mr/hr at predetermined radiation survey points on the barrier.

(6) Locations of monitors and assistants during the exposure.

6.9.8.4.1 The completed form SHALL be maintained on file for three years. If a suspected overexposure occurs, any other documents generated during the subsequent investigation SHALL be filed with the respective utilization log. When a log is completed, the radiography supervisor (lab chief) will sign the log.

6.9.9 NDI Facility Design and Modification.

6.9.9.1 Determining Shielding Requirements. The structural shielding requirements of any new installation or of an existing one in which changes are contemplated, MAY be decided by a Health Physicist, Radiological Physicist, Nuclear Medicine Science Officer, or a qualified Bioenvironmental Engineer, provided it is approved by the appropriate Headquarters.

6.9.9.2 Data Required for Determining Shielding Requirements. To adequately determine shielding requirements, the following data concerning the source of radiation SHALL be provided:

a. Type of radiation source (e.g., X- or gamma-ray).

b. Maximum and average tube potential (kilovoltage) or the energy of the radiation source.

c. Maximum and average tube current (milliamperage) or the source output in roentgens per minute at one meter (R/min) from the source.

d. The expected workload in milliampere minutes (mA-min) per week.

e. The use factors for each wall, floor, and ceiling as appropriate. This is the fraction of the workload during which the useful beam is pointed in the direction under consideration (see Table 6-34).

f. The type of occupancy of all areas which might be affected by the installation (see Table 6-35).

g. The structural details of the building. This will include a dimensioned drawing of the facility, with notation of the typical distances from the X-ray source to each barrier of the facility, as well as the expected construction materials for the facility.

Table 6-34. Use Factors (U)*

Installation Use	Enclosed	
	Collimated Sources	Open Sources
Floors	1	1
Walls	1/4	1
Ceilings	1/16	1
* For use as a guide in planning shielding when complete data are not available.		

Table 6-35. Occupancy Factors (T)

Full Occupancy (T = 1)	X-ray control space and waiting space, darkrooms, film reading areas, workrooms, shops, offices, and corridors large enough to hold desks, living quarters, children's play areas, occupied space in adjoining buildings.
Partial Worker Occupancy (T = 1/4)	Worker restrooms, occupational use corridors too narrow for desks.
Partial Occupancy (T = 1/8)	Public corridors too narrow for desks, utility rooms, and employee lounges.
Occasional Public Occupancy (T = 1/20)	Rest rooms or bathrooms, storage rooms, vending areas, outdoor areas with seating.
Rare Occupancy (T = 1/40)	Outside areas used only for pedestrians or vehicular traffic, unattended parking lots, attics or crawl spaces, stairways, unattended elevators, janitors closets.
* For use as a guide in planning shielding where adequate occupancy data are not available.	

6.9.9.3 Direction of Useful Beam.

a. Although the cost of shielding MAY be reduced significantly by arranging the installation so the useful beam is not directed toward occupied areas, the cost of shielding SHALL NOT override potential safety concerns. However, since weapon system requirements can change during the useful life of a facility, shielding SHALL be adequate enough for any future requirements which may occur.

b. Devices that permanently restrict the direction and cross section of the useful beam MAY reduce the area requiring primary barriers.

6.9.9.4 Radiation Energy, Output, and Workload. The shielding for each occupied area SHALL be determined on the basis of the expected maximum kilovoltage or energy, mA or R/min, workload, use factor, and occupancy factor affecting it. Consideration SHOULD be given to the possibility the values of these parameters MAY increase in the future. It MAY be more economical to provide a higher degree of protection initially than to add to it later.

6.9.9.5 Structural Details of Protective Barriers. Shielding for radiographic installations is normally provided by installation of sheet lead, or concrete. Facilities where high workloads and gamma-ray sources are used, MAY use a combination of these materials, or use concrete loaded with high iron content aggregate to improve shielding efficiency. The half-value layers of lead and concrete (the thickness of each material necessary to reduce the exposure intensity by a factor of two) for various energy X-rays and gamma rays is shown in Table 6-36.

Table 6-36. Peak Voltage (kVp)

HALF-VALUE AND TENTH-VALUE LAYERS						
Attenuation Material						
Peak Voltage	Lead (mm)		Concrete (cm)		Steel (cm)	
kVp	HVL	TVL	HVL	TVL	HVL	TVL
70	0.17	0.52	0.84	2.8		
100	0.27	0.88	1.6	5.3		
125	0.28	0.93	20.	6.6		
150	0.30	0.99	2.24	7.4		
200	0.51	1.7	2.5	8.4		
250	0.88	2.9	2.8	9.4		
300	1.47	4.8	3.1	10.4		
400	2.5	8.3	3.3	10.6		
500	3.6	11.9	3.6	11.7		
1000	7.9	26	4.4	14.7		
2000	12.5	42	6.4	21		
3000	14.5	48.5	7.4	24.5		
4000	16	53	8.8	29.2	2.7	9.1
6000	16.9	56	10.4	34.5	3.0	9.9
Cessium-137	6.5	21.6	4.8	15.7	1.6	5.3
Cobalt-60	12	40	6.2	20.6	2.1	6.9

6.9.9.6 Quality of Protective Material. All shielding materials SHALL be of assured quality, uniformity, and permanency.

6.9.9.7 Lead Barriers. Lead barriers SHALL be mounted in such a manner they will not cold-flow because of their own weight and SHALL be protected against mechanical damage. Additionally, lead sheets at joints SHOULD be in contact with a lap of a least one-half inch, or twice the thickness of the sheet, whichever is greater. Welded or burned lead seams are permissible provided the lead equivalent of the seams is not less than the minimum requirement.

6.9.9.8 Joints between Different Materials or Structures. Joints between different kinds of protective materials SHALL be constructed so the overall protection of the barrier is not impaired. Additionally, joints at the ceiling SHALL be constructed so the overall protection is not impaired.

6.9.9.9 Shielding of Openings in Protective Barriers. In the planning of an installation, careful consideration SHOULD be given to reducing the number and size of all perforations of protective barriers and openings into the protected areas. Protection for all such openings SHALL be provided by means of suitable protective baffles.

a. Perforations. Provision SHALL be made to ensure nails, rivets, or screws which perforate lead barriers are covered and give protection equivalent to the unperforated barrier.

b. Openings for Pipes, Ducts, Conduits, Louvers, etc. Holes in barriers for pipes, ducts, conduits, louvers, etc., SHALL be provided with baffles to ensure the overall protection afforded by the barrier is not impaired. These holes SHOULD be located outside the range of possible orientations of the useful beam.

c. Doors and Observation Windows. The lead equivalent of doors and observation windows of exposure rooms, cubicles, and cabinets SHALL NOT be less than required for the walls or barrier in which they are located.

6.9.9.10 General Requirements for Doors.

a. Location of Doors. Where practical, doors into exposure rooms SHOULD be located so the operator has control of access to the room.

b. Interlock Switches for Doors. All door(s) and panel(s) opening into an X-ray exposure room or cabinet (except those opened or removed only with tools) SHALL be provided with single interlocking switches preventing irradiation unless the door or panel is closed. Double doors SHALL have interlock switches that operate independently of each other.

c. Resumption of Operation. If the opening of a door or panel to a: "Protective," or "Enclosed" installation has interrupted the operation of any radiation source, it SHALL NOT be possible to resume operation by merely closing the door or panel in question. To resume operation, it SHALL be necessary to re-energize the source at the console, and this procedure SHALL cause the time delay interlock system to be reinitiated. It SHALL NOT be possible to resume operation by merely re-engaging the interlock.

d. Escape or Interruption of Irradiation from Inside Exposure Room. The exposure room SHALL include at least one means of exit that MAY be rapidly opened from the inside. A suitable means SHALL be provided to quickly interrupt irradiation from inside the room. The means of accomplishing this SHALL be explained to all personnel and a sign explaining its use SHALL be conspicuously posted inside the exposure room. Preferably, the beam SHOULD NOT be directed toward the door or interrupting device.

e. Threshold Baffle for Door Sill. A door baffle or threshold will generally be required for radiography sources and for installations operating above 125 kVp, if the discontinuity can be struck by the useful beam.

f. Lap of Doorjamb. The protective lead covering of any door leading to an exposure room or cabinet SHALL overlap the doorjamb and lintel so as to reduce the radiation passing through clearance spaces to the allowable limit for the door itself.

SECTION X COMPUTED RADIOGRAPHY

6.10 GENERAL CAPABILITIES OF COMPUTED RADIOGRAPHY.

6.10.1 Introduction to Computed Radiography. Computed Radiography (CR) has emerged as a leading environmentally safe technology for recording a radiographic image similar to the ways that film radiography has been practiced for decades. CR offers many advantages over conventional film-based radiography. The most prominent advantages are the increase in productivity, ease of archiving and retrieving images, use of powerful image processing tools to qualitatively improve images, greater thickness latitude with same or better contrast sensitivity and in many applications, a lower x-ray dose to inspect the object. CR enhances productivity as image processing is accomplished in a very short time without the dependence of chemicals or water. Computed Radiography (photo stimulated luminescence method) can be described in simple terms as a two step radiographic imaging process; first, a storage phosphor imaging plate (IP) is exposed to ionizing radiation both x-ray or gamma; second, the luminescence from the IP's photo stimulable luminescent phosphor is detected, digitized and presented via a high resolution display monitor.

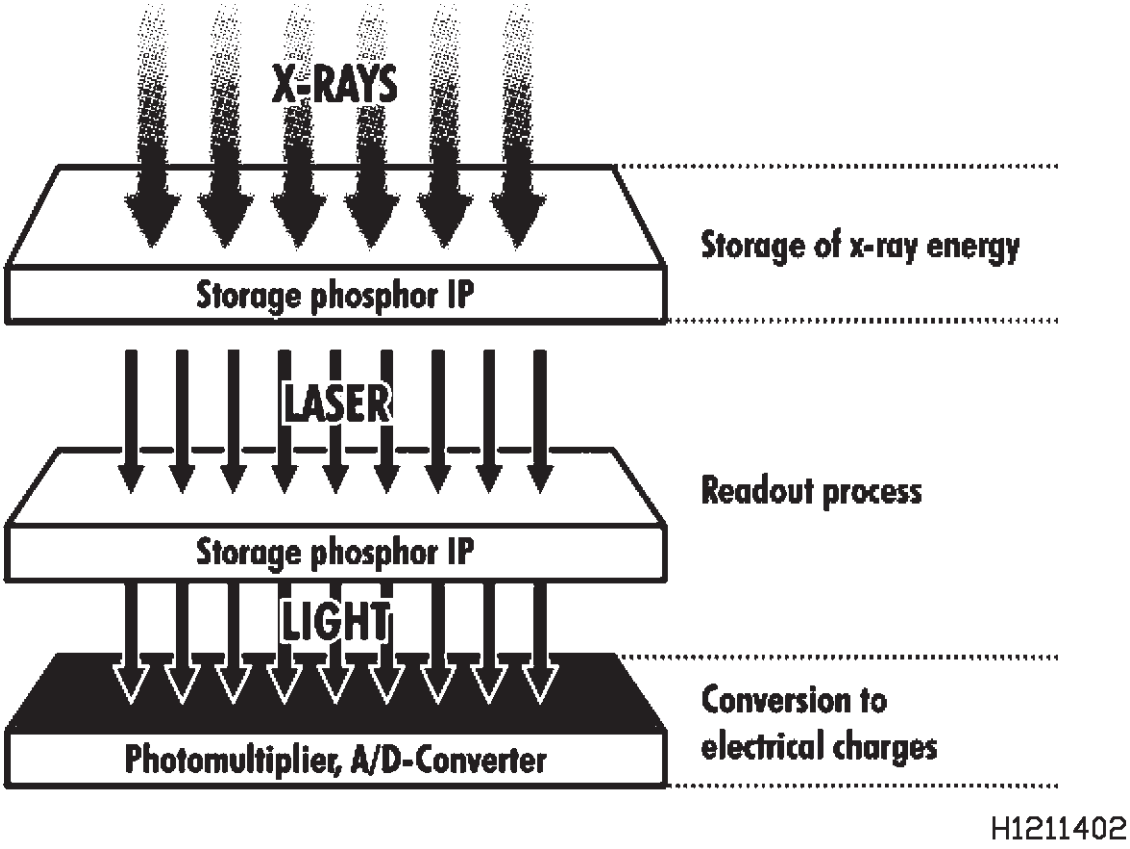

Figure 6-74. Example of Computed Radiography

6.10.1.1 CR-to-film comparison. CR is similar to film-based radiography as it utilizes the same radiation source but it differs in how the image is captured and processed. Rather than using conventional radiographic film, CR uses a flexible phosphor imaging plate (IP), which is exposed in the same manner as film but is processed using a CR reader or scanner. In simple terms, the reader uses a laser to convert the energy recorded in the IP phosphors into light, and the light output is converted into a digital image which can be evaluated using each manufacturer's unique CR software. Compared to conventional radiographic film, CR typically can produce improved contrast sensitivity as well as increase the image "latitude," being able to image a wider range of densities in one exposure as compared to film. However, conventional high

resolution film is still considered to have superior spatial resolution than CR, primarily because the film contains silver halide grains on the order of 0.5-3.0 microns in diameter (ASTM E 1815-96 Class I), while state-of the-art CR systems typically sample data at a resolution of 25 to 100 microns (pixel size). Although CR pixels are relatively larger than film grains, detection of fine defects (e.g., cracks, microporosity) is dependent on the combination of spatial resolution, contrast sensitivity, and signal-to- noise ratio (SNR).

6.10.1.2 CR Application. Most Department of Defense aerospace inspections are low energy (<160kV) applications that fall into two general categories: those that can be performed with low spatial resolution/low SNR (i.e. FOD, water, honeycomb), or those that require high spatial resolution/high SNR (i.e. airframe cracks, welds). Guidance for weld inspections using CR is planned to be published in TO 00-25-252, when authorization is given. The following guidance is specifically related to low energy applications.

6.10.1.2.1 System Selection. Like film systems, CR systems can vary in capability. IPs can range from coarse grain to fine grain (like film), and IP readers can sample the data at low or high resolution. In addition, many other CR system variables, which will be discussed in later sections, can significantly influence the image quality. In most cases, a coarse or medium grain IP used with an IP reader with low sampling resolution can produce acceptable radiographs for low spatial resolution/low SNR applications. Conversely, a fine grain IP used with an IP reader with high sampling resolution may be required for high spatial resolution/high SNR applications.

6.10.1.2.2 Technique Development. For low spatial resolution/low SNR applications, technique development is fairly straightforward and often results in lower kV and/or shorter exposures than film. However, for high spatial resolution/high SNR applications, technique development must take into account other critical factors to ensure the required spatial resolution and SNR are achieved. As a result, CR techniques for these applications may or may not be similar to the equivalent film technique.

6.10.1.2.2.1 Total Image Unsharpness. For applications with high resolution requirements, total image unsharpness is critical to image quality. Total image unsharpness is influenced by geometric unsharpness as well as the characteristics of the IP and IP reader. Total image unsharpness must be validated by determining the visible wire pair using an unsharpness gauge (ASTM E2002) placed at the appropriate position in the object plane. This validation is typically performed by the technique developer and not required to be revalidated during the inspection.

6.10.1.2.2.2 For applications with high signal-to-noise ratio requirements, the exposure (mA x time) must be sufficient to achieve the required SNR. SNR measurement tools are not available on all CR systems, and CR systems that do have SNR measurement capability may not use the same algorithm to calculate the value. As a result, an alternate method independent of system software tools uses a test standard called the Equivalent Penetrameter Sensitivity (EPS) standard to establish the required exposure and minimum pixel value (image intensity) for a given CR system. For USAF crack detection applications, the energy (kV) and minimum exposure (mA x time) is established by the technique developer for each approved CR system and provided in the inspection procedure. Typically for crack detection inspections, the technician may adjust the energy of the technique to achieve the minimum pixel value, but can only increase (not decrease) the exposure.

6.10.1.2.2.3 Scatter. CR is inherently more susceptible to the effects of scatter radiation than film due to the nature of IP materials and construction. However, most low energy applications are not significantly affected by secondary scatter radiation. The effects of scatter are typically evaluated during technique development, and if identified may be reduced or controlled through use of x-ray tube filtering, lead screens, or technique adjustments.

6.10.1.3 The basic steps of the CR process include:

6.10.1.3.1 Step 1: Exposure of the object. Using the approved procedure, the test object is exposed to ionizing radiation.

6.10.1.3.2 Step 2: Image capture. An Image plate (IP), in place of film, is exposed to the ionizing radiation and a latent image is created.

6.10.1.3.3 Step 3: Scanning of the IP. Depending on the CR system, the technician will enter pertinent information into the acquisition software before or after the scanning operation. The exposed IP is placed in the reader, often using a hard cassette specific to the system, and the IP is scanned with a laser (red) stimulating light causing photostimulable luminescence (PSL) “bluish” light to be released from the IP. This light is collected by optics and channeled to one or more photomultiplier tubes (PMT). The computer processes the information received and the software allows the viewing of the image data.

6.10.1.3.4 Step 4: Viewing/Post Processing. The image is displayed on a high resolution viewing monitor (typically monochrome). Technicians evaluate the image according to the inspection procedures, and may add appropriate labels or

annotations. During this step, contrast and brightness (also known as window and level), as well as magnification, are often adjusted by the technician. In some cases, select post-processing filters may be authorized.

6.10.1.3.5 Image Storage/Filing. The original data file, processed CR image (if required), and any annotations are saved and are retrievable based on archival requirements.

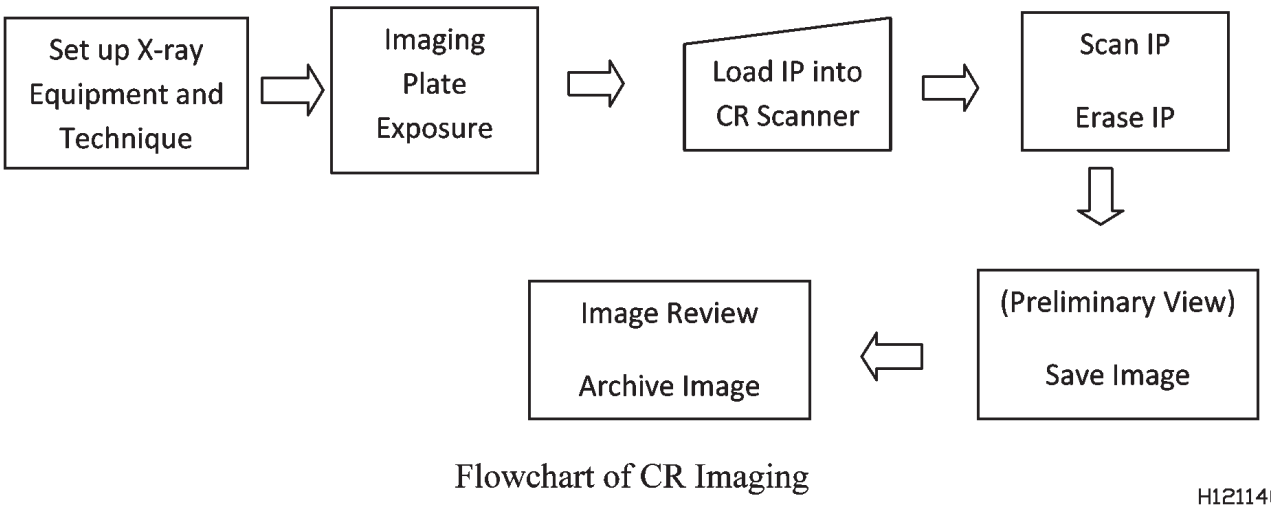

Figure 6-75. Flowchart of CR Imaging

6.10.2 Computed Radiography System. The CR system is comprised of several components, each of which affects the inspection process. The primary components include Imaging Plates, CR reader, CR eraser (normally part of the reader), computer workstation, and a high resolution monitor.

6.10.2.1 Imaging Plates. A phosphor imaging plate (IP) is a flexible two-dimensional area detector in which the latent image of the test part is stored after the test part is exposed to the penetrating radiation. The primary function of the IP is to release the radiation input signal containing part information into a corresponding optical signal while preserving the maximum amount of part information.

6.10.2.1.1 IP Construction.

6.10.2.1.1.1 IPs are made using the same type of polyester plastic substrate as modern x-ray films. They are produced in sizes similar to commonly available films. IPs typically include additional layers to control the emitted light and an outer coating to seal and protect the sensitive layer from moisture and abrasion. Unlike most x-ray films, IPs are all single-sided, and the thickness of the sensitive layer is greater than for film emulsion layers. Optimum imaging performance is obtained when the sensitive layer faces the x-ray source. Severely degraded image quality and physically inverted images will result if IPs are mistakenly exposed “backwards”.

6.10.2.1.1.2 IPs contain a phosphor layer of fine-grained, barium fluorohalide crystals doped with a divalent europium (Eu2+). These IPs are coated on a polyester support and a polymer overcoat that provides protection against normal handling such as fingerprints and moisture. A polycarbonate backing layer provides anti-halation protection with flexibility and stability. When the IP is exposed to x-rays, electrons of the IP are excited to a higher energy level and are trapped in halide vacancies to form color centers. Holes created by the missing valence electrons cause Eu2+ to become Eu3+. These thin phosphors layer of fine-grained barium fluorohalide crystals captures the energy within the phosphor creating a latent image. The latent image will degrade over time but remains relatively stable for several hours.

6.10.2.1.2 IP types. Many types of IPs are available. Like film, different IP types may have different grain sizes. In general, fine grain IPs are preferred for high resolution applications requiring high SNR (e.g. detection of fine cracks, microporosity), and large grain IPs for low resolution applications requiring low SNR (e.g. detection of foreign object debris, large defects). In many cases, one IP type may be suitable for multiple applications.

6.10.2.1.3 IP Handling and Wear.

6.10.2.1.3.1 The normal wear-out mechanism for IPs is mechanical damage or abrasion. When the protective layer becomes scratched, the image quality is degraded. Thus, the life obtained varies dramatically with the care and cleanliness used in handling the IPs. In some applications, where the IPs are never directly handled and remain in rigid cassettes during storage and exposure, they can remain useful for many thousands of uses. However, some types of the high-resolution IPs needed in fine-detail aerospace inspections use thinner and softer protective layers that are more susceptible to physical damage, so extreme attention to handling conditions is needed to avoid premature scratching of these IPs.

6.10.2.1.3.2 Particular care should be used to keep all cassettes, screens, and sleeves that come in contact with IPs free of dust and debris. IPs should be handled only by their edges to prevent skin oils and fingerprints from contacting the active surface. (Minor scratching or contamination of the backing surface does not directly affect IP performance or image quality, but can cause the trans-port of dust and abrasives into cassettes, readers, or erasers.) (Technicians could use cotton gloves to aid in keeping IPs clean) Only manufacturer-recommended cleaning solutions and procedures should be used on the IPs if removal of surface contaminants is required. Caution is required, since different manufacturers recommend differing and, sometimes, incompatible cleaning solutions and methods for their IPs.

6.10.2.1.4 Cassettes for exposure. IPs can be exposed within typical vinyl cassettes utilized in film radiography, or within a rigid cassette if provided by the manufacturer. When utilized without rigid cassettes IPs are typically flexible enough to wrap around a 1-inch diameter tube. Depending on the CR reader, a rigid cassette may be necessary for processing.

6.10.2.1.5 IP shapes. Depending on the type of CR reader, non-standard IP shapes (i.e. other than 8x10-inch, 14x17-inch) may or may not be permissible. The manufacturer should specify if non-standard shapes can be handled by their reader. In some cases, a special cassette may be required for processing non-standard shapes.

6.10.2.1.5.1 Cut IPs. IPs are typically thin and can easily be cut with scissors or a sharp knife. Compromising the edge seal could make the IPs prone to moisture damage at the edges. Often, manufacturers may recommend cutting tools and materials for sealing IP edges after cutting. In these instances, IPs can be shaped to meet specific application and/or imaging needs. Handling and attention to detail is required to prevent damage to the IP and to prevent creation of artifacts that may interfere with interpretation.

6.10.2.1.6 IP Erasure. Prior to each exposure, IPs must be erased. This is a separate step from the readout process, since readout alone does not remove all stored image information from a previously exposed IP. Erasure of IPs is accomplished through exposure to bright white light from fluorescent or halogen lamps, either in the reader device (automatic) or in a separate eraser. Direct sunlight is also very effective at erasing IPs, but the protective coatings on certain older IPs can be damaged by its strong UV spectrum, so use of the manufacturer’s erasure procedures and equipment should be followed.

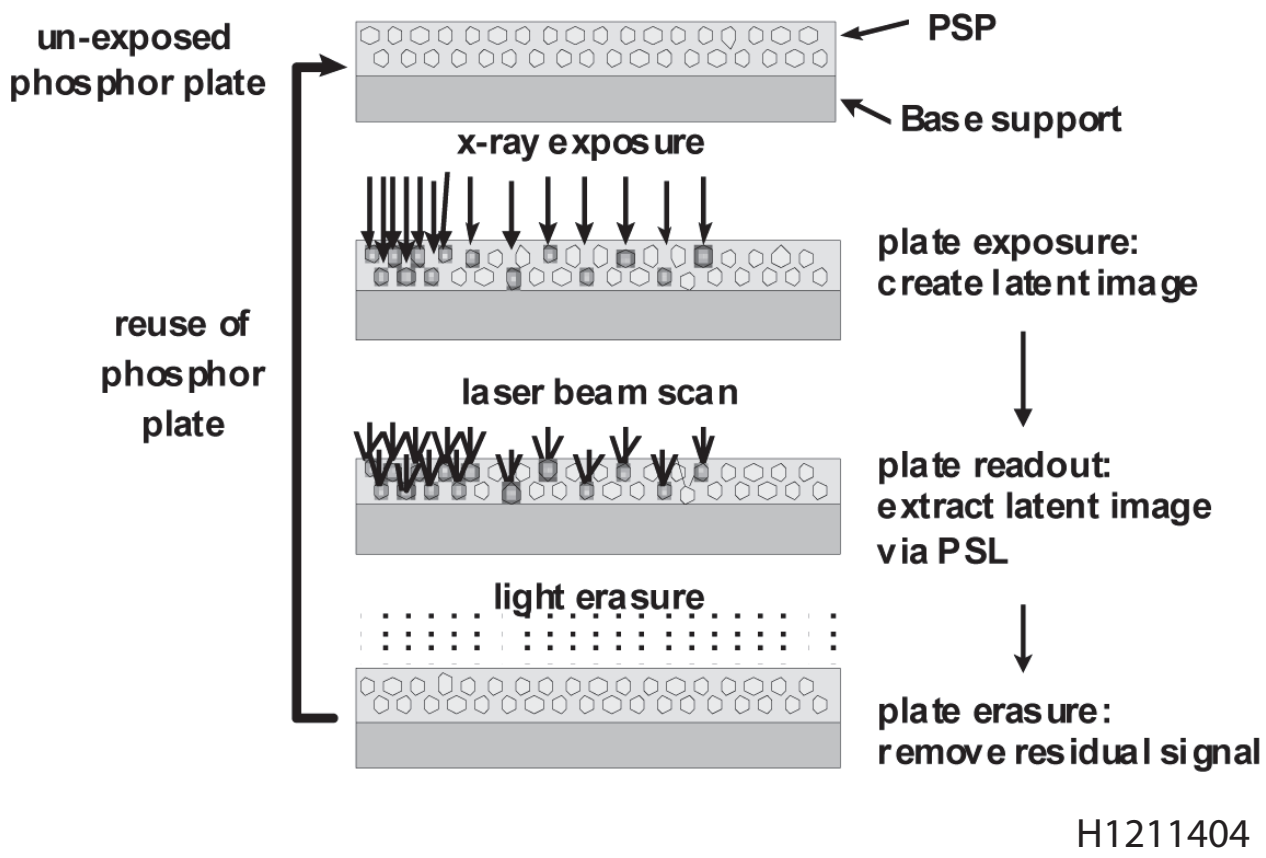

Figure 6-76. Example of IP Erasure

6.10.2.1.7 Residual Images.

6.10.2.1.7.1 The sensitive layer of IPs consists of small crystals of a barium fluorobromide or barium fluorobromoiodide material that absorbs energy from incident x-rays and stores that energy in excited states of the crystal structure. The CR crystals are, typically, much larger than the silver halide grains in industrial films. This allows for greater thickness of the sensitive layer and, consequently, improves x-ray absorption efficiency. The thickness of the sensitive layer and the crystal size can be tuned to adjust the speed and resolution of the IP. At the kV ranges used in many common inspections, the thickness and composition of the sensitive layer can make IPs somewhat more sensitive to scattered radiation than typical films; thus, in some inspections, a slightly lower kV setting, increased part-IP distance, or additional front screens are needed to compensate.

6.10.2.1.7.2 In all materials, the majority of electrons excited by x-rays decay back to normal energy levels in a prompt fashion, immediately releasing their energy back to the crystalline structure. But, the IP material also has metastable states that allow excited electrons to become “stuck” in a decay path that takes a longer time to relax. These states store the image information when the IP is exposed.

6.10.2.1.7.3 The image storage mechanism of the crystals does not wear out or become used up. Barring mechanical damage, IPs can be reused indefinitely for multiple exposures because of this inherent material property. However, there also can exist a small concentration of defect states caused by crystal imperfections. These can trap excited electrons and prevent them from finding the metastable states, thus, affecting the image storage efficiency. The defect trap states can persist for weeks, or even months, at room temperature.

6.10.2.1.7.4 In severe cases, the defect traps can cause residual or “ghost” images that can be very difficult to erase. Ghost equalization (e.g., exposing IPs to high doses followed by repeated erasure) is recommended by some IP manufacturers to recondition IPs with residual images, while others recommend exposing affected IPs to wide-spectrum ultraviolet light (e.g., direct sunlight). Any IPs that exhibit objectionable residual images cannot be used for inspection. Therefore, exposure techniques that subject IPs to extreme exposure contrasts should be avoided (e.g., very long exposures at low kV that are sometimes attempted when trying to achieve contrast in both thin and thick regions of small parts that do not fully cover the entire IP). Residual images can be reduced or eliminated with lead masking when the test article does not cover the entire imaging plate. If authorized for the application, pre-filters (at the x-ray tube) or screens (front/back of IP) may also help.

6.10.2.2 CR Reader/Eraser.

6.10.2.2.1 The reader/eraser is the component that will take an exposed IP, scan the IP using a laser light, capture the light emitted from the IPs, and provide the necessary information to the computer workstation. Following the exposure to the laser light, the eraser will expose the IP to white light causing the IP to be returned to a state for future use.

6.10.2.2.2 The characteristic time to naturally relax the excited metastable states is, typically, many hours at room temperature – allowing up to 24 hours in some applications between exposure and readout. However, if a red light photon is absorbed by an excited electron in a metastable state, it can then decay promptly through an alternate decay path, releasing its stored energy in the form of a blue light photon. This process is at the heart of CR: by “tickling” an electron that was previously excited by an absorbed x-ray with a red laser, it emits a blue light photon. This process is known as Photo-Stimulable Luminescence (PSL), and a material with this characteristic is called a Photo-Stimulable Phosphor (PSP). By measuring the amount of blue light emitted, the amount of absorbed x-ray dose is inferred, as shown in Figure 6-77.

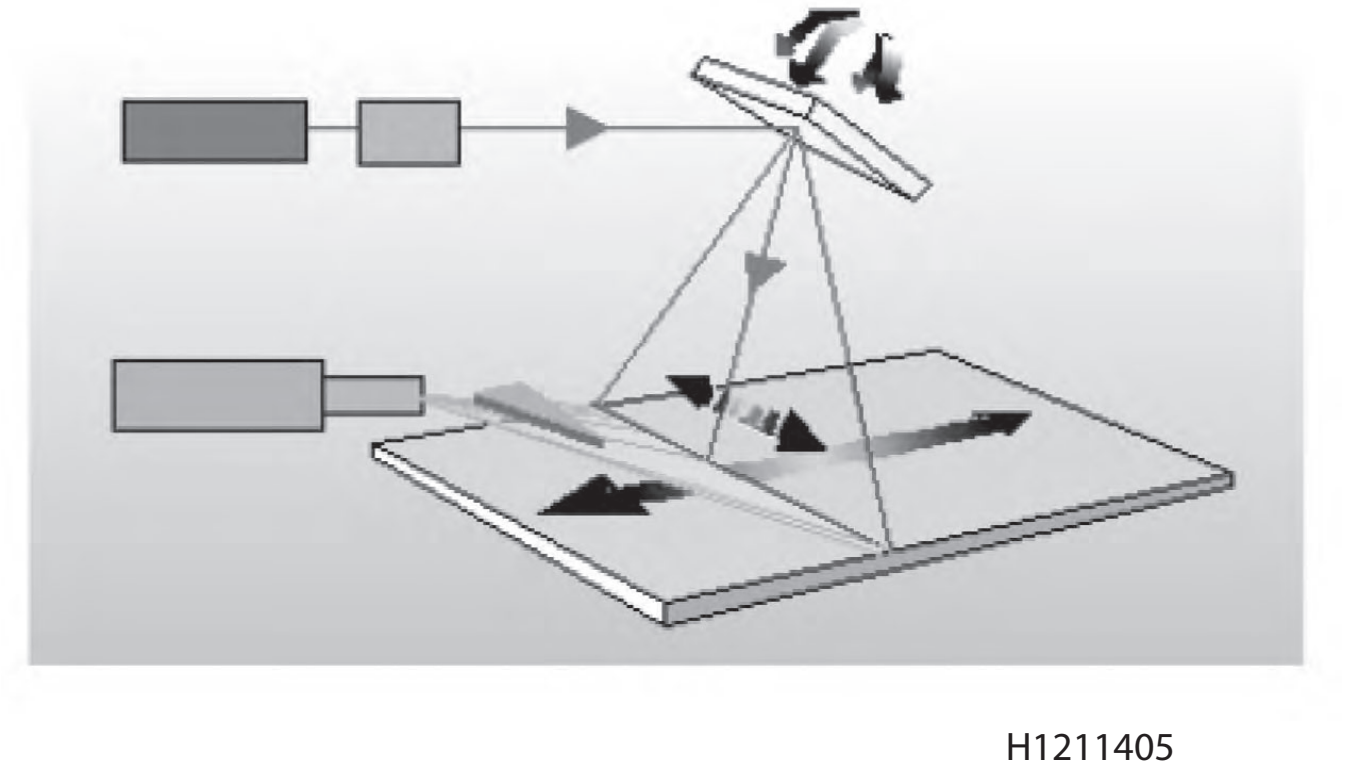

Figure 6-77. Flying Spot CR Reader

NOTE

The “Flying Spot” CR Reader sweeps a spot of Red Laser across the IP while the IP is being moved in the transverse direction. The Blue Light emitted from the IP is directed to a PMT. Each measurement sample (in time) yields a corresponding pixel (in space) for the resulting digital image.

6.10.2.2.3 The “flying spot” CR reader is not an imaging system like a camera or microscope, and the emitted blue light is not focused to an image receptor. Various readers use different methods to gather, or guide, the blue emission light into the PMT, but none focus light from points on the IP to an image receptor. Rather, the CR “image” is formed by sampling the PMT output in time and associating each measurement with the location of the red laser during that time interval. Referring again to Figure 6-77, the PMT “views” a large area of the IP, so any and all blue light emitted can be gathered and measured.

6.10.2.2.3.1 Laser.

6.10.2.2.3.1.1 The red laser light is focused to a small, roughly circular area called the focal spot. The size of the spot varies between readers and influences the smallest image features that can possibly be spatially resolved by a particular reader. However, the actual image resolution limit is determined by the size of the blue emission spot, not the smaller red laser spot. The IP, ordinarily, contributes a significant degree of additional image unsharpness. The relatively large size of the CR crystals affects the absorption and scattering of visible light during the readout process. The larger crystals absorb less light and reduce optical losses, which allows for the increased thickness of the sensitive layer. However, they also have an increased tendency to scatter visible light, both the red excitation light and the blue emitted light. This material property causes some of the optical light to scatter sideways in the IP (i.e., perpendicular to the incident x-ray beam). Thus, the blue spot is larger than the red spot, causing additional blurring and unsharpness during the readout process.

6.10.2.2.3.1.2 In addition to the actual focal spot size of the red laser and the lateral scattering of red and blue optical photons in the IP, a third factor also affects the area of the blue light “seen” by the PMT at any moment: the decay time of the excited metastable states. The emission of blue light is slightly delayed from the absorption of the red stimulation light and the typical delay time is a significant fraction of the PMT sampling time. Thus, the shape of the moving blue emission area exhibits a slight smearing, or “tail”, opposite the direction of motion. These 3 factors combine to determine an effective readout spot size. Generally, none of these optical blurring factors is adjustable by users, so the limiting spatial resolution is fixed by the selection of reader model and IP type.

6.10.2.2.3.2 Spot Size.

6.10.2.2.3.2.1 The effective readout spot size is not inherently round, but tends to be elongated in the “fast scan” direction of the “flying spot” motion. However, the final spatial resolution is also affected by the sampling period. The effective spot moves during the sampling period, adding greater unsharpness to the image. Thus, the image resolution is often better in the “slow scan” direction than in the fast, requiring CR resolution testing to be performed in both vertical and horizontal image directions.

6.10.2.2.3.2.2 The time required to read out an entire IP is inversely proportional to the laser sweep speed and users must often wait while IPs are being read and erased, so the fastest useful speed is normally used. Thus, for a given laser sweep speed, the rate of sampling determines the size of the image pixels. The sweep speed is user-adjustable in some CR readers and most allow the sampling rate to be adjusted indirectly via a pixel sampling size adjustment. However, most CR image acquisition software programs provide a single adjustment that controls the laser speed, digitization rate, and the slow scan IP motion speed to achieve samples that are equally spaced in both directions. However, as explained above, the area represented by each sample period may not be square in shape and the actual spatial resolution may not be the same in both directions.

6.10.2.2.3.3 Sampling resolution (a.k.a. scan resolution). The “best” sampling resolution for a particular IP/reader combination may not be obvious. The effective spot size is usually not a published specification, so technique developers often tend to try the smallest available spot size setting for a given reader. However, setting the sample resolution smaller than the effective readout spot size will not improve image resolution, but instead, can significantly degrade image quality because of increased measurement noise. In principle, any type of IP can be scanned at any sample resolution; there is no such thing as a “50 micron IP”. However, scanning at a sampling resolution smaller than the effective laser spot size is counterproductive, and scanning at a coarser sample resolution will reduce the available image resolution (although perhaps yielding a faster readout cycle time). Thus, all settings affecting the sample resolution for a particular inspection should be controlled as key technique variables.

6.10.2.2.3.4 Laser Power. Some CR readers have an adjustment for laser power. Since the laser brightness is, ordinarily, insufficient to stimulate emission from all of the latent image states, the maximum power setting available usually results in optimum signal-to-noise performance. Exceptions can occur when high power settings degrade the laser focus, so guidance from the reader manufacturer should be followed.

6.10.2.2.3.5 PMT Gain. Most CR readers have an adjustable gain setting that affects the amount of electric current produced by a given amount of light. If the gain is too low, the dynamic range and stability of the PMT are affected. However, a too- high gain setting cannot compensate for information loss in noisy low dose images, as it will merely amplify the contrast information and the background signal alike. Thus, the PMT gain setting (sometimes called PMT voltage) should be as low as possible without affecting stable operation of the PMT. The PMT current is amplified prior to digitization, but the conversion from PMT output to the displayed result is not always linear (see LUT, paragraph 6.10.7.2). The set of digitized data measurements is stored as an array of digital data in a computer file.

6.10.2.2.3.6 Processing Cassettes. Depending on the CR system, processing cassettes may or may not be required.

a. Some systems use a hard cassette with an internal microchip which “tells” the reader at what resolution to sample the IP (i.e. 50, 100, 200 micron, etc.).

b. Some systems use hard cassettes with a transparent window, allowing the reader to “read” a barcode affixed to the IP to determine the sampling resolution.

c. Most systems however, do not require a special cassette, but require the user to select the sampling resolution through the workstation interface.

6.10.2.2.3.7 Operations. Although all readers operate similarly by transporting an IP past a scanning laser, specific features of readers can be drastically different. Some features to be aware of include:

a. IP handling. IP wear can be significantly different based on the reader design. Some drum type readers are more prone to score the surface of the IP as it is dragged across the surface of the drum. This primarily occurs on the non-imaging side of the IP, but over time, can affect image quality. Many other systems with internal rollers may cause minor IP damage, but most newer systems are designed to avoid abrasion of the IP surface and/or incorporate roller design that are very gentle on the IP surface. Some drum-type systems may also allow use of a “plate protector”, similar to a flexible cassette in appearance, which prevents abrasion on the IP surface as it is fed into the scanner.

b. Custom IP Handling. A common user requirement for airframe inspection is the ability to process custom shaped IPs. This is necessary in many cases due to access limitations (e.g. nearby structural interferences, etc.). With CR, some hard cassette systems will only process rectangular IPs in standard sizes (i.e. 8x10, 14 x 17 only), some systems can handle relatively simple custom shapes (e.g. hard cassette systems with custom "templates;" "drum" readers), and other systems can handle nearly any shape IP by employing unique features (e.g. glass cassette that remains closed during scanning; use of a sticky “carrier” plate that the cut IP can be laid on for transport through the reader). Likewise, for the less common requirement for the capability to process IPs of non-standard lengths (i.e. >17 inches), only a few reader models can accommodate.

c. Artifacts. Dust, lint, and debris can be trapped within a cassette or on an IP, so care must be taken to keep these areas clean. However, some reader designs are more prone to introducing contaminates that cause these artifacts, possibly due to location of internal optics, type of openings for transporting IPs, and/or airflow within the reader. Though not a significant concern for all applications, these contaminates appear as white artifacts and can be misinterpreted as defects (e.g. tungsten inclusions in welds).

6.10.2.3 Computer Workstation. The workstation typically controls both the acquisition and viewing of the CR image.

6.10.2.3.1 Acquisition interface. The acquisition interface allows the user to select pertinent reader settings prior to scanning the IP. The interface controls may be on the reader and/or within the computer workstation, depending on the CR system manufacturer and model. Selectable reader settings typically include sampling resolution, laser power and PMT gain (or equivalent). In some cases, one or more of these parameters is fixed. Acquisition software also typically provides data fields for inspection and technique information. In most systems, all image processing functions are controlled after the image is displayed, but in some cases the acquisition software may require selecting some image processing presets.

6.10.2.3.2 Image viewing interface. Once the reader has scanned the IP and displayed the image on the viewing monitor, controls are provided for viewing and post-processing the image such that the user can interpret the radiograph per specified

procedures. These controls typically include window/level, magnification, image filters, and various other tools. Use of these controls may be regulated by the specific inspection procedure.

6.10.2.3.3 Viewing Monitor(s). CR systems may have one or multiple monitors. In all cases, the monitor for viewing the CR image must be a high resolution monitor containing 3 or 5 million pixels (i.e. 3MP or 5MP). In most cases, the high resolution monitor is monochrome (i.e. black and white), but may be color. When a second monitor is employed, it is typically a low resolution monitor strictly for displaying the user interface. This low resolution monitor SHALL NOT be used to interpret CR images.

6.10.3 Display Conversion.

6.10.3.1 Display conversion is the process of changing digital bits to a visible representation. Note that the term “pixel”, or “picture element”, is used both to describe the area corresponding to a digital measurement sample, as well as referring to an individual discrete picture element on a computer monitor.

6.10.3.2 The format of the underlying digital data is determined by the CR reader and does not directly match the characteristics of the monitors used to display the radiographic image. Thus, all image viewing software provides for certain key functions (spatial re-sampling and gray mapping) and most platforms also provide the ability to perform additional optional functions (filtering, analysis, and annotation). Some platforms also allow a conversion of the data from the native format output by particular readers or to perform response normalization.

6.10.3.3 The various steps of the display conversion process can be separated into two groups: pre-processing (which occurs before the image data are stored in a computer data file) and post-processing, (which occurs afterward). Pre-processing steps are ordinarily irreversible, while post-processing can be reversed or modified by reverting to the stored data.

a. Pre-processing, typically, occurs either in the CR reader device or by the acquisition software immediately after image data are transferred to the controlling computer.

b. Post-processing usually occurs in real-time and is performed by the image display software on the image review computer, acting on a copy of the image data in volatile storage.

6.10.4 Point-to-Point Pre-Processing.

6.10.4.1 One common type of pre-processing is used to convert every pixel in a CR data image to an equivalent value in an alternate format. Various CR readers provide digitized data in different native output types, depending on the number of bits per pixel produced. Most common are 12-bit logarithmic, 12-bit square-root encoded, and 16-bit linear. The logarithmic data format allows a wide dynamic range of values and produces a display that resembles film radiographs in appearance. Square-root encoding produces a constant signal-to-noise ratio across the digitized output range. Linear data formats require more bits to span a similar dynamic range, but can be easier to interpret and ease exposure adjustments. Software systems that support multiple readers often allow changing data from all readers to a common default format, for instance, by switching data from native 12-bit logarithmic readers to 16-bit linear format. When selected, this conversion happens prior to image file storage, automatically substituting each distinct possible input value into its corresponding output value. This conversion ordinarily occurs with, essentially, no loss of information, but significantly alters the appearance of displayed images. When this type of processing is an option in a software package, it must be controlled as a key technique variable.

6.10.4.2 Another common type of pre-processing is normalization, sometimes called calibration. In most CR readers, the natural efficiency of the blue light gathering varies from side to side across the reader in the fast scan direction. Poorly normalized CR images will exhibit vertical stripes or bands, so most CR systems allow measurement of the left-to-right response variation, and then allow for each pixel from a given image column to be divided by the relative response, eliminating the vertical artifacts. (see TO 33B-1-2 WP 106 01, CR Process Controls, shading). This type of pre-processing also ordinarily results in no significant information loss.

6.10.5 Image Filtering.

6.10.5.1 Most software packages provide a number of digital processing filters that can be used to transform the data. Image filters, usually, process multiple data points to create a single output point, but without changing the number of image pixels. Thus, filter operations do not change the number of pixels in an image or the total amount of data being displayed.

6.10.5.2 Two types of filters are possible: temporal and spatial. In temporal filters, a single pixel location is repeatedly sampled and the samples are added to improve the signal-to-noise of the resulting image. Temporal filtering is, usually, a pre-processing operation; however, since an IP is ordinarily read only once before erasure, temporal averaging is rare in CR. Spatial filters are, typically, applied after the image data is stored as a post-processing step. In spatial filtering, multiple data points from nearby neighbors are added. If they are added equally, the effect is to average, or "smooth", the data. If some of the neighbors are subtracted, the effect is to enhance edges, or "sharpen", the data. Non-linear filtering is also possible; for example, the common median filter outputs the median of the image data values in the nearby neighborhood of each pixel.

6.10.5.3 Because filters combine many pixels into one, the order in which filters are applied is critical. For instance, the results of first smoothing, then sharpening, are noticeably different from first sharpening, then smoothing. Thus, if multiple filters are applied, the order of filtration must be controlled.

6.10.5.4 Filtering can emphasize some parts of the available information, but at the cost of making other information more difficult to visualize. Developing appropriate filtering often requires a detailed understanding of the data and noise characteristics. Demonstrating that a filtering process reliably enhances interpretation without masking otherwise-detectable indications can require significant rigor.

6.10.5.5 Note that some software programs apply proprietary filters as a pre-processing step when various material/inspection combinations are selected and do not retain the original data. These filters should be implemented only with caution, as this type or filtering is irreversible, and provides an opportunity for reducing the visibility of defect indications if improperly applied.

6.10.5.6 The use of filtration for final interpretation of CR images for challenging aerospace applications is not recommended at this time. Any preliminary interpretation using filtration shall be validated with the unfiltered image to ensure the filtration did not create or eliminate indications of interest. In any event, if filtering is employed, two controls should be applied:

a. The original unfiltered data should be retained as part of the inspection archive.

b. The exact sequence of filter steps should be specified in the inspection technique.

6.10.6 Spatial Re-Sampling.

6.10.6.1 The actual size of pixels on a LCD monitor is, typically, in the range of 0.150 to 0.300 mm, which is usually larger than the CR sample size corresponding to each data pixel (common sizes include 0.050 mm and 0.100 mm, i.e., 50 and 100 micron). The number of pixels in a digital CR image is, therefore, usually greater than the number available on the monitor used to view the images. Ordinarily, there is neither a 1-to-1 correspondence between a single data pixel and a single monitor pixel, nor does the size of the image displayed on the monitor match the actual size of the latent image that was captured on the IP.

6.10.6.2 The resampling adjustments that determine which data pixels are displayed in each monitor pixel are commonly called pan and zoom. Zoom refers to adjusting the apparent magnification, or the number of CR data pixels that are displayed in a single monitor pixel. When the magnification is high enough that the full CR image corresponds to more pixels than are available on the monitor, pan refers to adjusting which region of the CR data are displayed and which portions are cropped. These adjustments are normally applied as a post-processing step and can be changed as needed to examine all regions of interest in a digital image.

6.10.6.3 There are three ways to characterize zoom: distance-to-distance, pixel-to-pixel, and image-to-image. In distance-to-distance, 1 cm on the IP corresponds to a variable number of cm on the monitor screen, independent of the CR sample size or monitor pixel size. In pixel-to-pixel, 1 CR data pixel corresponds to a variable number of pixels on the monitor. In image-to-image, the CR image is zoomed to fit a variable fraction of the monitor image window size. Different software programs use different names for these modes and few offer all three modes, so training with a particular package may be required to discern them.

6.10.6.4 The zoom factor is often expressed as either a ratio, a value, or as a percentage. For example, a magnification ratio of 8:1 also can be expressed as a magnification value or factor of 8, 8.0, or 800%. The simplest magnification is pixel-to-pixel mode at 1.0 or 100%, or 1:1, where each monitor pixel is used to display a single corresponding CR data pixel. Although this mode cannot remove aliasing that may be present in the underlying digital image, the 1-to-1 mode does not add sampling or aliasing artifacts and provides the optimum display fidelity. Other integer values of pixel-to-pixel zoom are free

of re-sampling artifacts, but zooming out to display more image pixels than monitor pixels still results in a possible loss of inspection information, unless the display area is carefully panned to examine all regions of interest.

6.10.6.5 All other zoom types and levels require either sub-sampling, averaging, interpolation, or replication of the CR data pixels before a derived data value can be calculated and may result in both artifacts and a loss of inspection information. Re-sampling artifacts, typically, appear as periodic diagonal or crosshatched bands or stripes in displayed images, but can be eliminated by choosing a pixel-to-pixel zoom mode. Again, different software programs use different format conventions for the zoom factor values and few offer all three modes, so training with a particular package may be required to determine optimum display procedures.

6.10.7 Gray Mapping.

6.10.7.1 Typically, the digital radiograph data has between 12 (4096 gray levels) and 16 bits (65536 gray levels) of contrast information available. Human eyes cannot distinguish even 4096 distinct gray levels, but only somewhere between 7 and 10 bits (i.e., 128 to 1024 levels) of gray. Thus, not all of the contrast information can be viewed at any given time. The mapping adjustments usually take longer to change than lightbox controls and must be adjusted in discrete steps. Gray mapping is ordinarily a post-processing step and, thus, is adjustable and does not result in irreversible information loss.

6.10.7.2 Gray mapping is implemented using a Look-Up Table (LUT). This is simply a table or list of output gray levels for each possible input level. Since grays are a subset of the color display spectrum, this method can be used to create color maps as well. These maps are normally called “pseudo-color”, or false color maps, and are commonly used in the display of data from other NDT modalities such as ultrasound or eddy current testing. Pseudo-color displays do not provide a uniform perception of contrast across the range of displayed values, but tend to emphasize contrast in the data regions that are mapped into transition regions between bands of differing hue. Because of the smaller monitor pixels and calibration features available in gray-only monitor, grays also can be viewed on color monitors, and it is often desirable to make digital x-ray data appear film-like, gray mapping is usually preferred for the display of digital radiographs.

6.10.7.3 The LUT is typically calculated using a ramp function. A ramp function specifies the mathematical formula for changing input digital values (corresponding to measurements of x-ray absorption) into output gray values (for display on a monitor, film, or hard-copy print). The ramp function has only a few parameters that can be adjusted. The most common ramp function is linear, where the shade of displayed gray is varied so that the optical light intensity varies in direct proportion to the digital data values, as shown in Figure 6-78. Only two parameters describing the slope and midpoint of the middle portion are required to specify the ramp function.

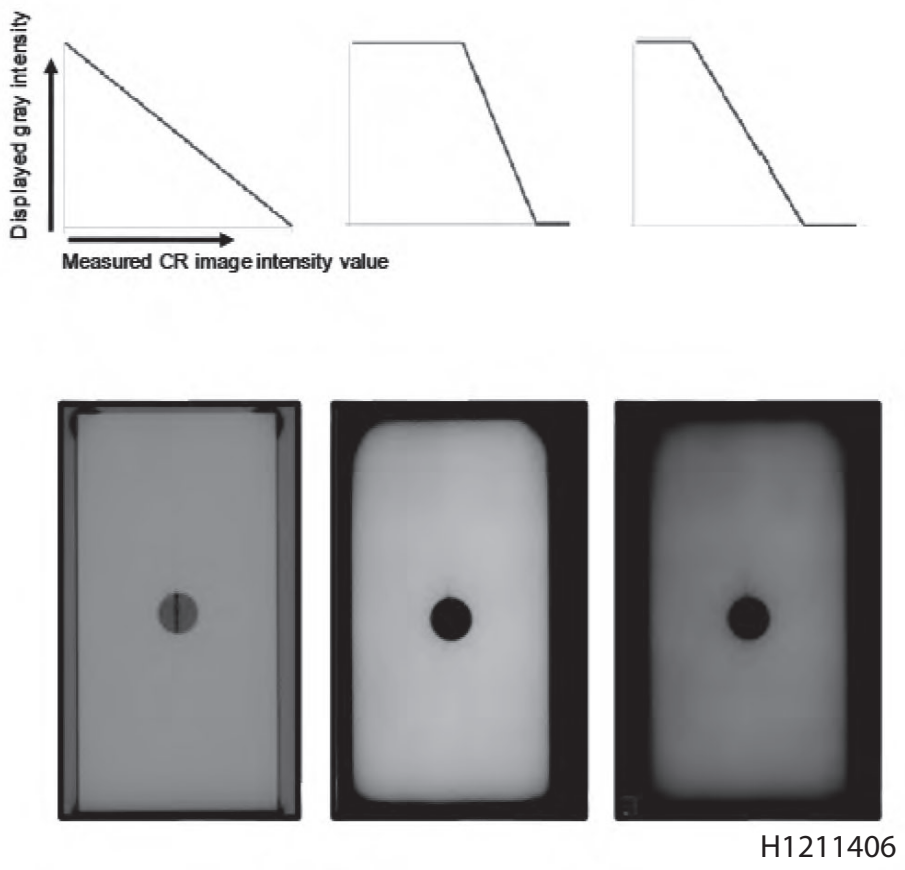

Figure 6-78. Conversion Linear Ramp Function

6.10.7.4 Thus, the absorbed x-ray intensity at a small region on the IP is directly translated into optical light intensity at a monitor pixel for viewing. Terms like window and level, center and width, or contrast and brightness are used to describe the mapping of data values into grayscale brightness, depending on the software used to display the radiographs. CR images, typically, must be viewed using multiple sets of window/level settings to examine all part thickness ranges at full contrast sensitivity.

6.10.7.5 Non-linear grayscale ramp functions are also available in some software packages. Logarithmic ramp functions can mimic the optical density response of x-ray film from 16-bit linear image data and display a wide latitude of part thicknesses in a single ramp adjustment. “S-shaped” sigmoid ramps also increase latitude while keeping high contrast for mid-range data.

6.10.7.6 Because the display of the CR images depends upon features that vary between different software packages, the package and version used for inspections should be specified in the technique and documented as part of the inspection record. Particularly if various possible defect indications require differing gray mappings for optimum display, appropriate ranges for these ramp parameters can be specified in the technique.

6.10.7.7 These adjustments allow detailed examination at full contrast resolution across a wider latitude of part thicknesses than could be viewed in a single image. The adjustments can have a strong impact on the visibility of low-contrast defect indications. CR inspection images often must be examined using multiple sets of window and level adjustments to verify IQI sensitivity and span the required range of part thicknesses. If the CR data are to be archived after inspection, the ramp function type and the parameters used for interpretation of defect indications in displayed images should be recorded as part of the inspection records.

6.10.7.8 Many software programs also provide an unrelated type of gray mapping called “histogram equalization”. This type of gray mapping is based on the actual distribution of intensity values within the specific digital image. By ranking the intensity distribution in the image according to the number of pixels that exhibit the same intensity, the equalization process results in a displayed image where the same number of pixels are assigned to each gray level displayed. This is not a spatial or temporal filter and does not have a simple quantitative function between input data values and output gray levels, but does provide a method to display the entire dynamic range of data in a single view.

6.10.8 Adding Annotations and Analysis.

6.10.8.1 A number of graphical tools are available in most image review software packages, including measurement tools and annotation tools. These allow the user to add markings to the displayed image showing geometrical measurements (e.g., distances, angles, etc.) or to add captions and arrows pointing to features of interest. These tools can be useful to document inspection results. The majority of software programs for CR add these elements to a displayed view in real-time as a post-processing operation and allow for their removal or repositioning, thus, are safe to use as needed.

6.10.8.2 The annotated displays can be archived in two ways. Most software packages can store a “recipe” for the post-processing steps (including annotation and analysis) and, thus, recreate a display for documentation or reporting purposes. However, these recipes may not easily translate from one software package to another and are, typically, unavailable to users of generic image display programs on common computers. Thus, most software programs also provide the ability to “export” displayed views, typically, by writing the 8-bit pixel values displayed on the monitor into a computer file using a common picture file format. In this case, the exported images usually have any annotations permanently added to the view and the wider 12-bit or 16-bit dynamic range of the original image data is lost. These exported views are useful for documentation and reporting and can inserted as figures into word-processing and presentation files for sharing with non-specialists, but often are not sufficient for archiving of inspection results.

6.10.9 Viewing Room Ambient Light. Subdued lighting in the viewing room is preferred rather than total darkness. Background illumination lighting shall be arranged such that light reflections do not interfere with review of the images. Background ambient light levels should not exceed 30 lux (3fc); light levels shall be measured at the monitor surface, with the monitor off. The interpreter should wait sufficient time, after entering the viewing area, before interpreting images.

6.10.10 Process Controls. A variety of process controls have to be accomplished on CR systems to ensure the systems are operating at the required level of performance. The intervals of the test and the method of performing process control are published in SWP 106 01 of TO 33B-1-2.

a. Monitor test. The Society of Motion Pictures and Television Engineers (SMPTE) have produced a standard SMPTE RP-133 that contains a standard electronic image for evaluating most of these display parameters. Process control tests require visual evaluation of the pattern to evaluate the contrast, brightness, spatial resolution, and overall performance of the monitor.

b. Imaging Plates Artifact Documentation. The artifact test evaluates the CR image for non-relevant indications inherent to the imaging plate. (i.e. scratches, nicks, etc.)

c. Reader System Evaluation. There are several test accomplished using the USAF CR Process Control Standard (CRPCS) or the NAVAIR Phantom.

(1) Contrast Sensitivity - evaluate the ability of the CR system to detect variations in image intensity.

(2) Spatial Resolution - evaluates the ability of system to detect and distinguish between features.

(3) Geometric Distortion - evaluates the image to determine if it is distorted in the X and/or Y axis.

(4) Laser Jitter - evaluates the image to determine if a lack of smooth movement of the imaging plate and laser scanning device occurs.

(5) Slippage - evaluates the image to determine if lines of data in the image are uniformly spaced.

(6) Scan Line Dropout - evaluates the image for lucent or bright white straight lines oriented in the long or “slow scan” direction.

(7) Blooming or Flare - evaluates the image for evidence of overrun or streaking in areas with high density contrast.

(8) Shading - evaluates the image for non-uniform intensity across the scanning width, evident as either as a gradual change in the shade of gray in the "scan" direction or as "bands" of shading in the "feed" directions.

(9) Residual image - evaluates the erasure performance to ensure a residual image does not remain on the IP which can affect interpretation of future images.

d. For AF crack detection and welder certification applications, an additional check is required using the Equivalent Penetrameter sensitivity (EPS) standard. This test measures a parameter analogous to signal-to-noise ratio, but is independent of CR system software.

6.10.11 Tools Used in Image Interpretation With the Software. Many of the following terms may vary by manufacturer.

a. Windowing and Leveling - Window (contrast) and Level (brightness) controls are commonly used to adjust the image to allow the appropriate contrast sensitivity in the area of interest. (e.g. thick and thin areas in same image may require different window and level settings to interpret properly, although a large window setting may display the entire image with decreased contrast)

b. Area Adjust - Software automatically adjusts window and level of entire image or region based on minimum and maximum brightness levels within a region.

c. Pan/Scroll - Allows the image to be grabbed and moved in any direction in the image viewing area.

d. Magnification/Zoom - Zoom refers to adjusting the apparent magnification, or the number of CR data pixels that are displayed in a single monitor pixel. The simplest magnification is pixel-to-pixel mode at 1.0 or 100%, or 1:1, where each monitor pixel is used to display a single corresponding CR data pixel. The 1:1 mode provides the optimum display fidelity. Zooming out to display more image pixels than monitor pixels may result in a loss of inspection information, unless the display area is carefully panned to examine all regions of interest.

e. Area Zoom - Allows user to select a portion of the image for magnification.

f. Calibrate - Allows for calibration against a known dimension within the image.

g. Ruler - Allows user to make length measurements.

h. Region of Interest (ROI) - a selection of the image in which measurements are being made (e.g. pixel statistics, signal-to-noise ratio, etc.).

6.10.12 Digital Image, Data Archival and Retention.

6.10.12.1 Digital Image Storage and Archival, Storage for the digital images varies from CDs, DVDs, portable hard drives to intranet/network solutions. The media of choice should be carefully evaluated to maintain the images per the user requirement and/or their customer requirements. The format in which the images are to be archived for retrieval should also be decided with long term future parameters defined. Most digital image systems do not compress their images and store the original raw data. The storage solution should also include a backup copy of digital data at all times.

6.10.12.2 CR system manufactures typically provide shared software or light simple function software so that the images can be shared with colleagues and customers that require the ability to evaluate the raw images. Exporting and or saving the raw image to an accepted digital format such as Tiff, JPG, and or Bitmap along with many other formats is a typical function that requires standardization by the user and/or their customer requirements.

6.10.12.3 Compression. Image compression techniques for digital images fall into two main categories, "lossless" and "lossy" compression.

6.10.12.3.1 Lossless compression. Lossless compression techniques are the only compression styles universally accepted by the industrial digital radiography community. In a lossless compression algorithm, the original raw data can always be reconstructed exactly as it was before compression. There is no loss of the original information; it is just coded in a way that is smaller for storage.

6.10.12.3.2 Lossy Compression. Lossy compression techniques sacrifice some of the image data to create even smaller file sizes while trying to maintain the overall quality of an image. The amount of loss can vary in most techniques, and is determined by the quality factor used in the compression algorithm. Lossy compression techniques degrade an image over each subsequent compression from a decompressed image in a manner similar to making a noisy copy of an analog cassette tape, then making a copy of a copy, using the same equipment. The original raw data is lost and irretrievable in a lossy compression technique. Examples of lossy compression include: “Discrete Cosine transform” compression, standard “JPEG” compression, and "wavelet compression methods. Of these, wavelet compression tends to produce the highest quality copy with a high compression ratio and low image loss.

6.10.12.4 Digital Imaging and Communication in Nondestructive Evaluation (DICONDE). Most CR systems incorporate DICONDE for managing the CR database. The basic concept of DICONDE is to implement standardized tag identifiers for every part of the CR data stream as well as communication protocols. CR systems that are “DICONDE compliant” have the ability to record pertinent inspection information and store it along with the image file. A system that meets DICONDE interoperability requirements can also share data from other DICONDE systems (i.e. other manufacturers). More information on DICONDE can be found through ASTM and the Federal Working Group on Industrial Digital Radiography (FWG-IDR).

6.10.13 Computed Radiography Terminology.

Aliasing	Image artifacts that appear when the spatial frequency of the input is higher than the output is capable of reproducing. Typically appear as jagged/stepped sections in a line or as moiré patterns.
Bit depth	The number “2” increased by the exponential power of the analogue-to-digital (A/D) converter resolution. (e.g. a 16-bit system may have a maximum bit depth of 2^{16} = 65536)
Blooming or flare	An undesirable condition exhibited by some image conversion devices brought about by exceeding the allowable input brightness for the device, causing the image to go into saturation, producing an image of degraded spatial resolution and gray scale rendition.
Computed radiographic system	All hardware and software components necessary to produce a computed radiograph. Essential components of a CR system consisting of: an x-ray tube (or source), IP, IP reader, electronic image display (viewing monitor), image storage and retrieval system and interactive support software.
Computed Radiography	A radiological nondestructive testing method that uses storage phosphor imaging plates (IP’s), a PSL stimulating light source, PSL capturing optics, optical-to-electrical conversion devices, analogue-to-digital data conversion electronics, a computer and software capable of processing original digital image data and a means for electronically displaying or printing resultant image data.
Contrast-to-noise ratio (CNR)	Quotient of the digital image contrast and the averaged standard deviation of the linear pixel values.
CR phantom	A device containing an arrangement of test targets to evaluate the quality of a CR system, as well as monitoring the quality of the chosen system.
Digital dynamic range	Maximum material thickness latitude that renders acceptable levels of specified image quality performance within a specified pixel intensity value range.
Digital image contrast	Pixel value difference between any two areas of interest within a computed radiograph.
Digital image noise	Imaging information within a computed radiograph that is not directly correlated with the degree of radiation attenuation by the object or feature being examined and/or insufficient radiation quanta absorbed within the detector imaging plate.
Digital image processing	The use of algorithms to change original digital image data for the purpose of enhancement of some aspect of the image.
Equivalent penetrameter sensitivity (EPS)	That thickness of penetrameter, expressed as a percentage of the section thickness radiographed, in which a 2T hole would be visible under the same radiographic conditions.
Image morphing	A potentially degraded CR image resultant from over processing (that is, over driving) an original CR image.
Original digital image	A digital gray scale image resultant from application of original binary digital pixel data to a linear value prior to any image processing.

Photostimulable luminescence (PSL)	Photostimulable luminescence (PSL) is a physical phenomenon in which a halogenated phosphor compound emits bluish light when excited by a source of red spectrum light.
Pixel brightness	The luminous (monitor) display intensity of pixel(s) that can be controlled by means of electronic monitor brightness level settings or changes of digital driving level. pixel density—the number of pixels within a digital image of fixed dimensions (that is, length and width).
Pixel density	The number of pixels within a digital image of fixed dimensions (that is, length and width).
Pixel value (PV)	A positive integer numerical value directly associated with each binary picture data element (pixel) of an original digital image where gray scale shades are assigned in linear proportion to radiation exposure dose received by that area.
PSL afterglow	Continued luminescence from a storage phosphor immediately following removal of an external photostimulating source.
Signal-to-noise ratio (SNR)	Quotient of mean linear pixel value and standard deviation of mean linear pixel values (noise) for a defined detector area-of-interest in a digital image.
Storage phosphor imaging plate (IP)	A photostimulable luminescent material that is capable of storing a latent radiographic image of a material being examined and, upon stimulation by a source of red spectrum light, will generate luminescence (PSL) proportional to radiation absorbed.