Working Safely in Radiography

Previously published as *Working Safely in Gamma Radiography*
NUREG/BR-0024

The American Society for Nondestructive Testing

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Working Safely in Gamma Radiography was published in 1982 by the Nuclear Regulatory Commission as NUREG/BR-0024. It was written by Stephen A. McGuire, a health physicist and specialist in industrial radiography in NRC's Occupational Radiation Protection Branch, and Carol A. Peabody, a technical writer and project coordinator in NRC's Program and Administrative Services Branch.

Information covering protective enclosures, radiation quantities and units, and X-ray safety was adapted and reprinted from *Nondestructive Testing Handbook,* third edition, Volume 4, *Radiographic Testing,* published by the American Society of Nondestructive Testing.

The revision and update of this text was more intensive than a typical new book, requiring many hours of research to find the most current information. It would not have happened without dedicated reviewers. They include:
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Cynthia M. Leeman
Editor

Editor's Preface

This book was originally published in 1982 by the Nuclear Regulatory Commission as *Working Safely in Gamma Radiography* NUREG/BR-0024.

SI radiographic units.

Quantity	SI Name	Former Designation
radiation activity	becquerel (Bq)	curie (Ci)
radiation exposure	coulomb per kilogram (C/kg)	roentgen (R)
absorbed dose	gray (Gy)	rad
dose equivalent	sievert (Sv)	rem

Because the original publication is in the public domain, ASNT was granted permission to update and reuse that content. This book contained a great deal of very valuable information, but much of the book was out of date. In addition, it did not address X-rays.

To make this revision more useful, sections covering protective enclosures, radiation quantities and units, and X-ray safety were adapted and reprinted from *Nondestructive Testing Handbook*, third edition, Volume 4, *Radiographic Testing*, published by the American Society of Nondestructive Testing. The addition of X-ray safety resulted in the book's title change.

There are some items from the original text that could not possibly be updated, but are valuable. The information in the original Appendix F - Overexposure Accidents 1971-1980 (new Appendix D) is an example. The detail of the cause and result of each overexposure accident is very informative, but would be too time consuming to update.

The American Society for Nondestructive Testing is an International System of Units (SI) publisher. SI units are used throughout the text with centimeter-gram-second (CGS) units in parentheses. To minimize confusion, most equations are worked separately in CGS units and SI units.

Cynthia M. Leeman
Editor

Conversion to SI radiographic units.

Traditional Unit	Symbol	Multiply	Resulting SI Unit	SI Symbol
curie	Ci	3.7×10^{10} 37	becquerel gigabecquerel	Bq GBq
rad	rad[a]	10^{-2} 10	gray milligray	Gy mGy
rem	rem	10^{-2} 10	sievert millisievert	Sv mSv
roentgen	R	2.58×10^{-4} 258	coulomb per kilogram microcoulomb per kilogram	C/kg mC/kg

a. The abbreviation rd may be used for radiation absorbed dose where there is possibility of confusion with radian (rad), the SI unit for plane angle.

Reprinted from *Nondestructive Testing Handbook*, third edition: Volume 4, *Radiographic Testing*, Columbus, OH: American Society for Nondestructive, 2002, p. 31.

Preface

Who Is This Manual For?

This manual is designed for classroom training in working safely in industrial radiography using radioactive sources that emit gamma rays [and X-rays]. Industrial radiography using neutron sources is not covered in this manual.

The purpose of this manual is to help train you — a radiographer's assistant — to work safely as a qualified radiographer. This training is important to help you work competently as a radiographer and to help you prevent radiography accidents.

Industrial radiography using gamma ray sources is regulated by the U.S. Nuclear Regulatory Commission (NRC) or, in many states, by the individual states themselves. Industrial radiography using X-ray machines and accelerators is regulated by state regulatory agencies or by the federal Occupational Safety and Health Administration (OSHA).

This manual was written to assist your company in meeting the NRC's requirements on training radiographers. NRC regulations* require that individuals receive radiation safety training and pass both a written test and a field test before becoming radiographers. Each state that regulates gamma radiography has an equivalent requirement. This manual covers the general subjects that the NRC requires you to know about gamma radiography safety. Additional information on case histories of radiography accidents is available from the NRC.**

The radiography safety training information in this manual is intended to be taught by a qualified instructor using 40 classroom hours of instruction. This manual is not intended for self instruction. The instructor will be able to answer specific questions on equipment and procedures and will allow ample time for discussion with fellow students.

This manual does not cover your company's specific operating and emergency procedures. Your company's procedures for equipment operation, inspection and maintenance and the specific requirements in your company's license must be studied separately.

If you have already been instructed in your company's operating and emergency procedures, you will probably better understand the material presented in this manual. You will also get more out of the manual and the training course if you have worked as a radiographer's assistant using basic radiography equipment, especially radiography cameras and survey meters, for at least a month. This introductory work experience will help you to understand and appreciate more fully the safety information presented to you.

Stephen A. McGuire
Carol A. Peabody

*Title 10, "Energy," Part 34, "Licenses for Radiography and Radiation Safety Requirements for Radiographic Operations," Section 34.31, "Training."

**NUREG/BR-0001, Vol. 1, "Case Histories of Radiography Events."

Table of Contents

Chapter 1

Why Is Safety Training Important?

What Is Industrial Radiography?

Industrial radiography is the process of using radiation to *see* inside manufactured products such as metal castings or welded pipelines to find out whether the products contain discontinuities. The process is the same one that a medical doctor uses to X-ray a patient's chest or a dentist uses to X-ray a patient's teeth (Figure 1.1).

In industrial radiography, radiation is produced either by X–ray machines or by radioactive materials contained in small capsules. The radiation penetrates the object being studied and exposes X-ray film placed behind the object. Holes, cracks, impurities and other discontinuities in the object allow more radiation to reach the film. A picture (or radiograph) of the object has darker areas on the film where more radiation has penetrated. A person looking at the film can tell from these darker areas if there are discontinuities in the object. These radiographs can detect discontinuities in the components of airplanes, submarines, pipelines, bridges and power plants that could lead to dangerous accidents.

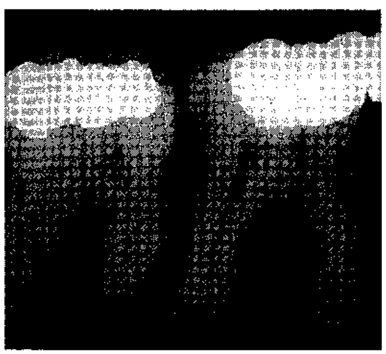


Figure 1.1: Dentists use radiation in the same way as a radiographer.

The Beginning of Radiography

The use of penetrating radiation in radiography is often thought of as a very modern development, but in fact using radiation in this manner is over a century old. The origins of industrial radiography go back to December 1895, when the German scientist Wilhelm Roentgen (Figure 1.2) discovered X-rays while experimenting with high voltage electricity in vacuum tubes. The X–rays he produced caused a fluorescent material to glow. Roentgen X-rayed a piece of metal to reveal variations in the metal. A year later, he made a radiograph of his shotgun that showed discontinuities in the barrels (Figure 1.3).

Figure 1.2: William Roentgen won the Nobel Prize in Physics in 1901 for the discovery of X-rays.

On New Year's Day 1896, Roentgen mailed his report of the discovery of X-rays to the leading scientists of Europe and into each envelope he slipped a handful of the pictures he had taken — the first X-ray pictures in the world (Figure 1.4). Within 2 months after Roentgen's announcement hospitals throughout the world

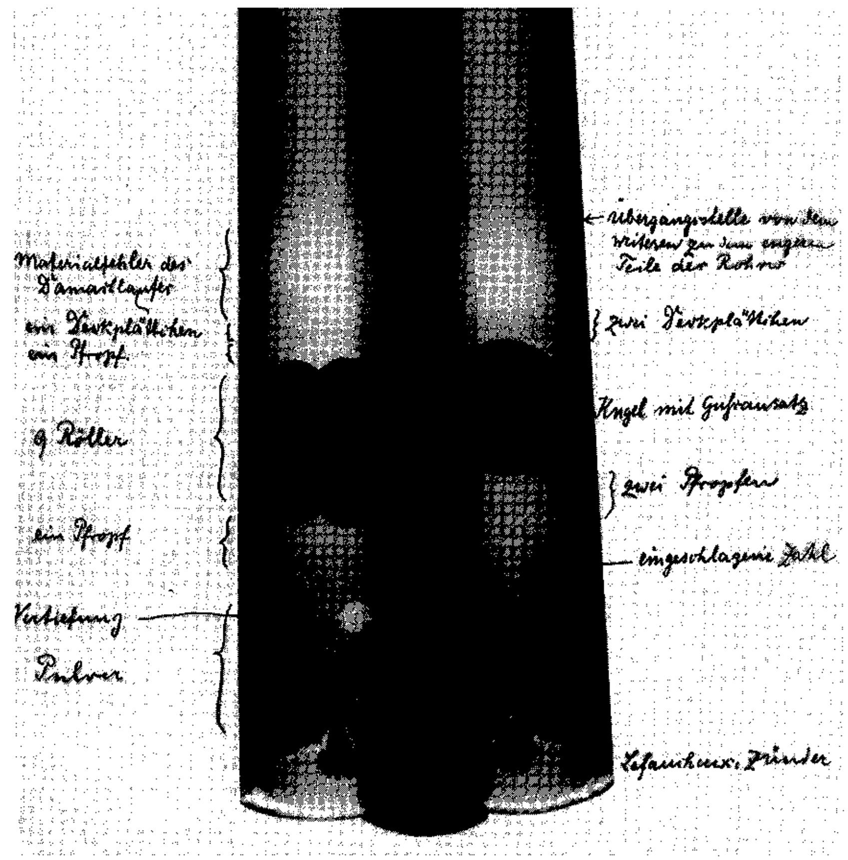


Figure 1.3: This radiograph of Roentgen's shotgun is the earliest industrial radiograph (1896). This radiograph shows erosion in the barrels. Exposure time was about 12 min.

were using X-ray pictures to aid in surgery (Figure 1.5).

Discovery of Radium

The discovery of X-rays led scientists to wonder whether any minerals within the Earth would also emit similar penetrating radiation. In 1896, French scientist Henri Becquerel discovered such radiation coming from a uranium bearing mineral.

Because Becquerel's rays were not intense enough to give pictures of bones, these rays were not nearly as fascinating as Roentgen's. The discovery was neglected for a year and a half. Then Marie and Pierre Curie, a wife and husband who worked together as scientists, discovered that uranium ore gave off much more radiation than expected. They suspected that another radiation emitter besides uranium was present.

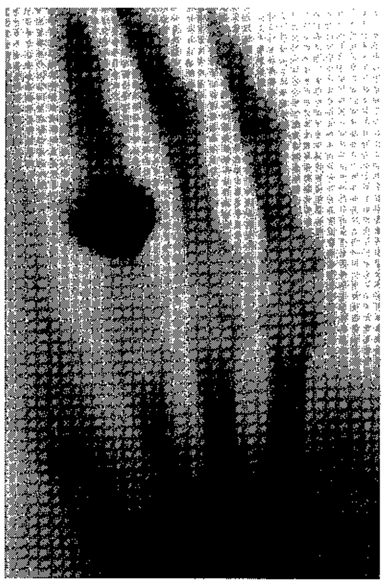


Figure 1.4: Mrs. Roentgen's hand was X-rayed December 22, 1895. Roentgen mailed X-ray pictures such as this in 1896 to Europe's leading scientists to announce his discovery of X-rays.

Figure 1.5: Within 4 days after news of X-rays reached the United States, hospitals used them to aid in surgery. In February 1896, a man's hand was X-rayed in order to aid in the surgical removal of more than 40 gunshot pellets (black spots in X–ray) embedded in the hand as a result of a hunting accident. Note the improvement in quality over Roentgen's original X–ray picture, Figure 1.4.

In 1898, after very tedious chemical separations, the Curies managed to produce a tiny amount of a previously undiscovered element from tons of ore. They named the element *radium* for the great intensity of its radiation,

At this point, the scientific basis for radiography using gamma rays existed, however, it would be 30 years before enough radium would be available for industrial radiography.

Early Gamma Radiography

Gamma radiography got its start in the United States in 1929 at the Naval Research Laboratory.[1,2] The Navy wanted a method to test thick steel castings, but X-rays available at that time could not be used for thicknesses greater than 7.6 cm (3 in.). Using radium, it was possible to radiograph castings up to 25.4 cm (10 in.) or 30.5 cm (12 in.) thick. The radium sources used then were very weak compared to modern sources. A source strength of one tenth of a curie was typical and exposure times of several hours to as long as 4 days were necessary.

Figures 1.6, 1.7 and 1.8 display an example of early sources. Industrial radiography grew tremendously during World War II as part of the Navy's shipbuilding program. Manufactured gamma ray sources such as cobalt and iridium became available in 1946, shortly after World War II. These new sources were far stronger than radium sources and were also much less expensive. The manufactured sources rapidly replaced radium and the use of gamma radiography grew quickly.

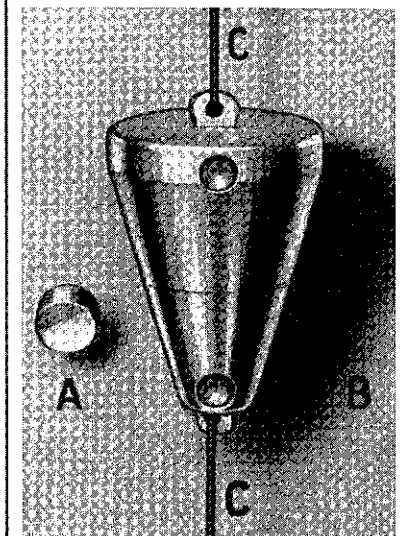


Figure 1.6: In 1940, radiography sources looked like this and usually contained about 3.7 GBq (0.1 Ci) of radium. The radium was sealed in a capsule (A) and placed in an aluminum-alloy container (B). This source was handled by using the cords (C) attached to the container.

Radiation Hazards

Industrial radiography is a powerful tool, but it involves some significant risks.

Exposure to harmful radiation is an occupational hazard that radiographers face. Three characteristics of gamma radiography make serious accidents possible.

1. Gamma radiography sources emit intense and penetrating radiation so that they can be used for studying thick metal samples. This means that these sources can expose the radiographer to a great deal of radiation in a very short period of time.
2. The best radiographs are produced by sources with the smallest dimensions. The radiation intensity on the surface of small gamma ray sources is enormous. Touching a source can cause serious harm.
3. Radiography is done under difficult working conditions with little direct supervision or assistance. On heavy construction projects, movement of pipes and beams by heavy equipment presents a constant hazard and distraction. In addition, there is constant pressure to finish the radiography work as soon as possible. The pressure to rush can lead to accidents.

If the radiographer understands radiation hazards and practices proper procedures when working with radiation, he can work with radiography sources without ever being overexposed.

Gamma radiography sources are composed of radioactive material enclosed in small stainless steel capsules. These sources emit intense radiation. If held in the hand, a typical source will cause radiation burns in seconds (Figure 1.9).

Very large doses of radiation to a small portion of the body may cause so much damage that amputation of the damaged tissue would be needed. The amputation of fingers, legs and portions of the torso and even death have been caused by radiography sources.

Most radiation overexposures caused by radiography accidents have not been large enough to cause radiation burns. However, even if the consequences of an overexposure are not seen immediately, long term effects such as cancer may occur many years later. Some people believe any amount of radiation received may increase a person's chances of developing cancer. For low doses of radiation, the risks are very small. The risks from

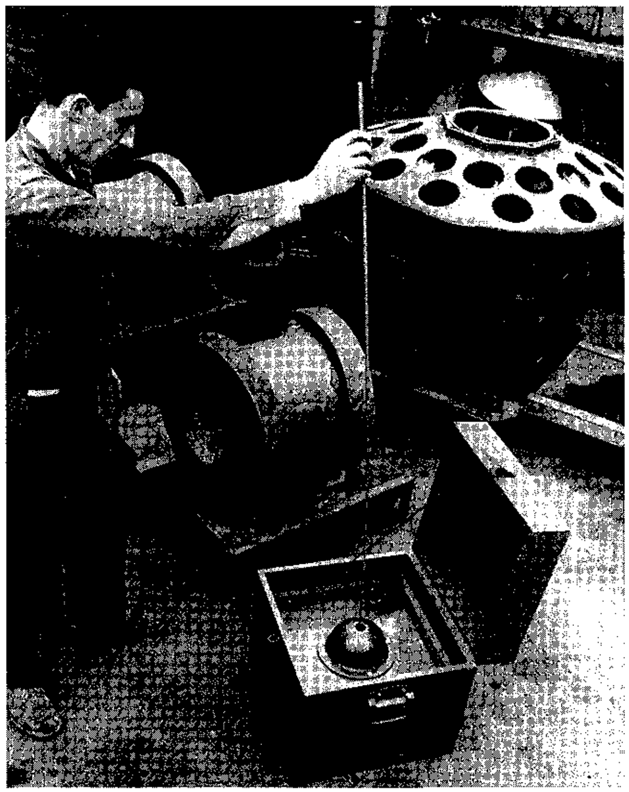


Figure 1.7: Early radium sources were handled using long *fishpoles* or cords. This method was suitable for weak sources. Better methods were needed to handle the stronger manufactured sources that became available during the late 1940s.

Figure 1.8: This picture of *fishpole* radiography was probably taken during the 1940s. The photo was obviously staged. The sources then available were so weak that exposures of an hour or more were necessary. Even the steadiest of hand could not be still long enough to avoid a blurry radiograph.

exposure to radiation are covered in Chapter 4.

Causes of Radiography Accidents

Most radiography accidents happen when procedures for working with radiation are not followed. Failure to follow proper procedures may be the result of rushing to complete a job, boredom, illness, personal problems, tiredness, lack of communication, poor training or a number of other factors.

Radiography accidents usually happen after the radiographer has made three separate mistakes:

- The radiography source is left out of the camera when it should not be.
- A required radiation survey to ensure that the source has been retracted to its shielded container is omitted or is not done properly.
- The radiography source is not locked into place once it has been retracted into the safe, shielded position.

These accidents can be avoided by following the company's operating and emergency procedures. These procedures are written so that radiographers can accomplish their jobs in a safe and efficient manner.

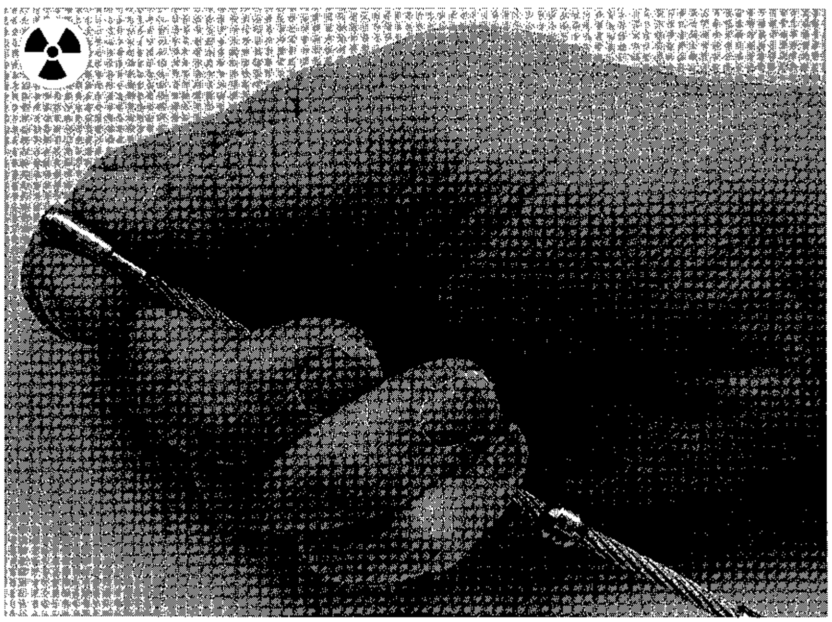


Figure 1.9: The radiation dose on the surface of a gamma radiography source is so enormous that, if held in the hand like this, radiation burns would be caused in seconds. (A dummy source shown between the thumb and forefinger, was used in this photo.)

When working with a radiography source, the radiographer is responsible for his own safety and the safety of others in the area. The ability to make the right decisions and take the right actions comes from a combination of training and experience. Studying the following chapters will help with the decision making process.

It should be clear that industrial radiography has hazards associated with it. The rest of this manual discusses the hazards in more detail as well as important safety measures that should be used to work safely in radiography.

Radiography Facilities[3]

There are many considerations involved in setting up and outfitting a safe radiographic facility. Commercial consulting firms specializing in personnel dosimetry and radiation protection may help with this goal. Regardless of who establishes or monitors the program, it is vitally important that radiation exposures to personnel be reduced to as low a level as is practical. Each radiographic facility should appoint a *radiation safety officer*, who is responsible for systematically assuring management that a safe operation exists. The functions of the radiation safety officer are discussed later in this part.

In the twenty-first century, some publications of the 1970s are still useful. All guidelines, standards, regulations and handbooks have a shelf life beyond which some of their information is obsolete. It is the duty of inspectors and safety personnel to become familiar with the literature and refer to up-to-date documents for critical decisions.

Because of potential changes in safety requirements, radiation safety officers and all personnel active in the field of radiography should consult the most up-to-date publications and regulations. Many publications are written specifically to describe in detail the requirements and techniques involved. The following is an overview of radiation safety and personnel protection. Note that safety regulations may vary with locality.

Radiation Safety Inspections and Audits Government Licensing[6]

Most manufacturers specify that radiation producing devices should be operated only by qualified personnel. Most states require the registration of radiation machines and provide survey services during compliance audits. Licenses to possess byproduct materials are issued by the Nuclear Regulatory Commission or Agreement States. The use of radium is no longer allowed.

Radiation Safety Officer

Personnel responsible for work with radiation are also responsible for radiation safety. Regulations require that a radiation safety officer (RSO) be appointed. The radiation safety officer must meet specific minimum training and experience requirements. The radiation safety officer is responsible for:

1. technical assistance in planning and execution of work regarding radiation safety,
2. appraisal of safe operation of the radiation source through surveys and personnel monitoring,
3. notification of personnel of any special hazards,
4. reporting of radiation hazards or unsafe practices to the proper authorities,
5. seeking advice from qualified experts when necessary,
6. keeping records of personnel exposures and area dose levels,
7. keeping informed of any changes in the mode of operation of the source and
8. providing radiation safety training.

The radiation safety officer must have access to any level of management necessary to ensure the compliance with regulations and procedures to provide for a safe work environment.

Written Procedures

Each licensee or registrant will have written operating and emergency procedures that at a minimum shall include instructions for appropriate handling and use of radioactive materials to maintain exposure to radiation below established limits. Operating and emergency procedures shall also describe methods and occasions for conducting surveys, methods for locking and unlocking radiography exposure devices and personnel monitoring requirements. Operability checks and equipment inspection and maintenance requirements must also be included in operating and emergency procedures. Additionally, requirements for transporting equipment to field locations and control of equipment during transportation must be included.

Emergencies

Company operating and emergency procedures shall provide information related to the steps that must be taken immediately by radiography personnel in the event a pocket dosimeter is found to be off scale or an alarm ratemeter alarms unexpectedly. Operating and emergency procedures shall include procedures for identifying and reporting defects and noncompliance and notifying proper personnel in the event of an accident or incident. Company procedures should include detailed instructions of actions to be taken to minimize exposure of persons in the event of an accident or incident, including a source disconnect, a transport accident, or loss of a source of radiation. If the company will perform source recovery, the operating and emergency procedures must include generic source recovery procedures.

Internal Inspections

An internal inspection system is essential to maintaining an industrial radiography program. Internal inspection programs are mandated by regulations and are vital to ensure safe operations and the welfare of radiography workers as well as of the general public.

Required internal inspections consist of semiannual radiographer audits, an annual overview audit of the entire radiation protection program, an annual review of the quality assurance program and a continuous review of the company program to keep personnel exposures as low as reasonably achievable (ALARA). Audit procedures for gamma radiography or X-radiography are basically the same, just as observations of temporary field sites are conducted in a manner similar to cell or permanent facility audits. These components make up the internal inspection system.

The single most important part of the internal inspection system is the radiation safety officer. The radiation safety officer should have sufficient experience and expertise to observe radiography operations and immediately recognize infractions or violations as well as good practices. The radiation safety officer should be able to make a valid assessment of the conditions observed and provide corrective actions or recommendations to those involved. Any and all discrepancies should immediately be pointed out to the responsible individuals with a followup notification to the appropriate supervision.

The radiation safety officer should conduct audits in person and take appropriate actions to stop violations or unsafe practices. Unfortunately some regulations are instituted as a result of the actions of a few individuals. The integrity of the radiation safety officer and the radiographers are important to a good radiation safety program. A good relationship between regulators and licensees is also important to a quality program. Regulators should not be feared or shunned:

avoidance gives the impression that people have something to hide.

The radiographers should be aware that the sole purpose of the radiation safety officer, observer or auditor at the job site is to validate that the radiography team is operating to the established procedures and within the restraints of governing regulations, not to try to catch the participants committing infractions. Systematic or generic deficiencies should be addressed to appropriate management for long term corrective actions. The audit process should be a positive experience rather than a traumatic one. A more casual, relaxed, audit allows an opportunity to experience the way things are done.

The better the auditor understands operations, the better the ability to identify existing or potential problems. Experience provides a higher potential to ensure the safety of personnel involved as well as the general public.

Personnel Certification for Radiation Safety[3]

The United States Nuclear Regulatory Commission has published rules that govern the use of nuclear, or gamma, radiation in those states that choose to follow federal regulations, the NRC states. In contrast, states that wish to use their own regulations, which must meet or exceed NRC requirements, are known as Agreement States and their regulations are in force for nuclear radiation in those states. Because X-rays (unlike gamma rays) are not generated by nuclear materials, the NRC does not have jurisdiction over X-ray radiography and each state is responsible for regulating X-radiography. Radiographers working in any state must be aware of who has jurisdiction over radiation safety and must adhere to the requirements that govern in that state. In some instances, large metropolitan areas also have requirements and these must also be met when working in those areas.

Safety Personnel Certification

In May 1997, the Nuclear Regulatory Commission published a rule requiring that all industrial radiographers using radioactive materials be certified through either an approved independent certifying organization or an Agreement State program that complied with 10 CFR Part 34, Appendix A – *Radiographer Certification*. The final deadline for compliance was July 1999 for NRC states and July 2000 for Agreement States.

The American Society for Nondestructive Testing developed the Industrial Radiography Radiation Safety Personnel (IRRSP) program, which was sent to the NRC for review in late 1997. In May 1998, the NRC formally approved the American Society for Nondestructive Testing as an independent certifying organization and accepted the radioactive materials portion of the Industrial Radiography Radiation Safety Personnel examinations.

The Nuclear Regulatory Commission does not take responsibility for radiation producing machines, such as X–ray machines used in radiographic testing. Each individual state is responsible for determining their own certification requirements for radiographers using X-radiation. The Agreement States, to minimize duplication and establish uniformity between the states' certification requirements, formed the Conference for Radiation Control Program Directors (CRCPD). In early 1998, the American Society for Nondestructive Testing asked this group to review the Industrial Radiography Radiation Safety Personnel program to determine if it would meet the requirements of the Agreement States.

In September 2001, the Directors formally approved the American Society for Nondestructive Testing as an independent certifying organization and recommended acceptance of the radioactive materials examinations and X-ray examinations for use by Agreement States.

Radiographer Certification

Radiographers are generally required to carry two types of certification, one based on technical competence and the other based on the knowledge of safety regulations. The requirements listed in commercial codes, standards and specifications are predominantly technical and rely on the employer to ensure that safety requirements are met. The safety requirements are detailed by the local, state or federal government regulatory agencies that have jurisdiction over radiography in the locale where the work is to be performed.

Technical certification is required by the code or standard governing a specific project. This certification ensures that the radiographer can make proper exposures and accurately interpret radiographs in accordance with the requirements of the code or specification. Each code or specification has varying technical requirements and each will specify that a radiographer be certified somehow before working on projects governed by those documents.

Safety certification is required by local, state and federal regulatory agencies. Because of the dangers of penetrating radiation, these agencies require a safety examination on the type of radiation to be used in the course of their work. To be eligible to sit for these safety examinations, radiographers must be able to show that they have had adequate training and experience in performing radiography.

Chapter 2

What Is Radiation?

Radiation — is it deadly or is it beneficial for the world? The word *radiation* causes all sorts of reactions these days. What are we to make of it?

On one hand, we hear that nuclear power is going to save an energy starved world. Some say the power of the atom will give an ocean of energy that can help produce our food, fuel our industries, recycle our precious minerals and restore our standard of living.

But we also hear about the radiation nightmare and the destructiveness of radiation. This nightmare is symbolized by mushroom clouds and giant chimneys looming over nuclear power plants. There is also the scare of geiger counters clicking rapidly, people dying of cancer and the horror of giving birth to mutated children — all because of an invisible danger. Most people do not understand radiation. This chapter will help to explain what radiation is.

A Form of Energy

Radiation is a form of energy. There are two basic kinds of radiation. One is tiny fast moving particles that have both energy and mass, referred to as *particle radiation*. These particles of radiation are similar to speeding bullets, but are so small they cannot be seen. Speeding electrons are radiation particles of this kind.

The other kind of radiation is pure energy with no weight. This radiation is like vibrating or pulsating waves of electrical and magnetic energy. *Gamma rays* are an example. The radiation waves are called *electromagnetic waves* or *electromagnetic radiation* and are referred to as *wavelike radiation* (Figure 2.1). Ordinary visible light is another form of wavelike radiation. All wavelike radiation travels as fast as the speed of light.

Energy must be used to produce light. In a light bulb, electrical energy is converted into heat (thermal energy). The filament of the bulb becomes white hot and emits light. The individual atoms of a white hot object shake very fast. Heat is the measure of how fast the individual atoms in a substance are moving. But it is a law of nature that when atoms are moving very fast, they will give off some of their energy in the form of wavelike radiation if anything changes their motion.

The most energetic light that human eyes can detect has a violet color. As the energy of the radiation particles increases, the light has gone beyond violet — it has become ultraviolet. It cannot be seen or felt, but it is still there and can give a suntan or a sunburn if the exposure is too great.

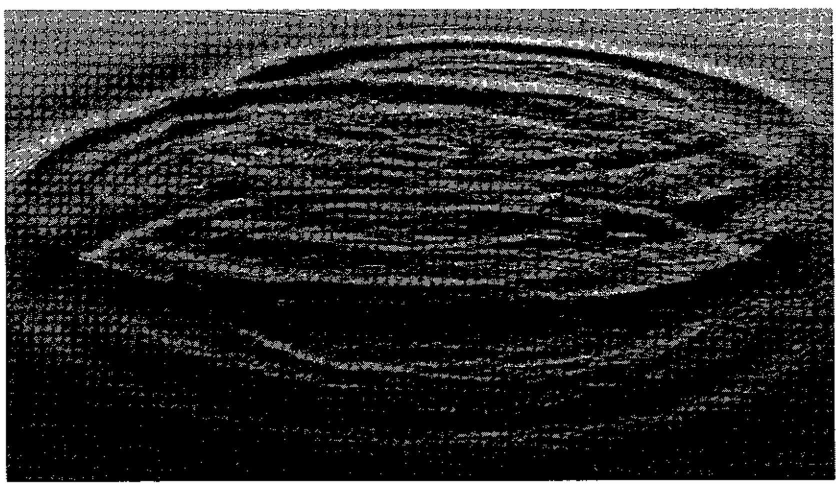


Figure 2.1: Wavelike radiation is similar to the waves made by dropping a stone in a quiet pond. The waves carry energy away from a disturbed point at the center. Visible light, radio waves, microwaves, X-rays and gamma rays are all wavelike radiation. The waves have both an electrical part and a magnetic part. Such wavelike radiation is called *electromagnetic radiation*.

X-radiation

To produce even more energetic radiation, electrons are made to travel at enormous speeds, smash into other electrons and thereby give off very energetic wavelike radiation. We call this type of radiation *X-rays*. X-rays have much more energy than visible light.

To produce these X-rays, very high electric voltages are used in a vacuum to produce an energetic stream of electrons. These high voltages cause the electrons to travel enormously fast. The electrons strike other electrons in a target material with incredible impact. The collisions are so violent that powerful waves of radiation are emitted in all directions. The radiation is *X-rays*.

Gamma Ray Radiation

A gamma ray is the same as an X-ray except that it comes from a different source. X-rays are caused by speeding electrons striking other electrons in a target. Gamma rays come from the nucleus or core of certain atoms that have too much energy. Some atoms have so much extra energy that the nucleus is constantly undergoing a violent shaking. Sooner or later something snaps. The nucleus can give up its extra energy by throwing off a tiny particle of an atom and a gamma ray. The gamma ray is a weightless radiation similar to light, but with much more energy. The tiny

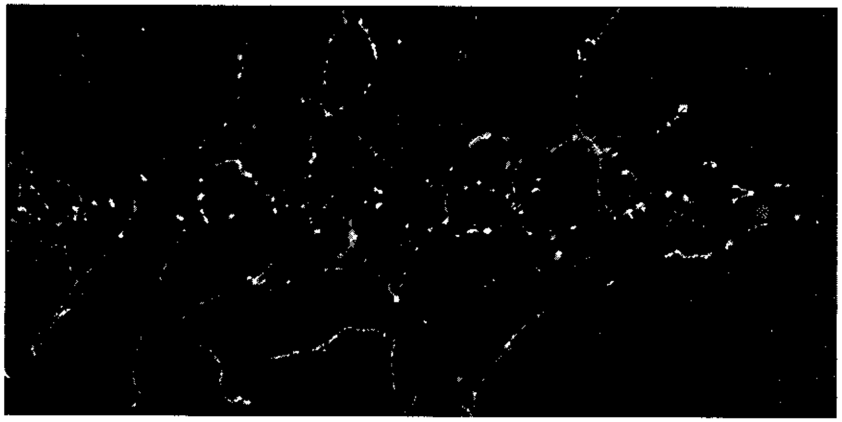


Figure 2.2: This historical photograph, published in 1923, shows the tracks made by electrons that have been hit by a narrow beam of X-rays. The X–rays pass through very moist air striking electrons in their path. These electrons speed off leaving a trail of electrically charged particles. Each particle becomes a center for the condensation of a visible droplet of water. The water droplets that are formed are photographed. C.T.R. Wilson, the scientist who took this photograph, won the Nobel Prize in physics for this work.

particle of the atom that is thrown off is also radiation, but it has weight as well as energy.

Collisions

When radiation as powerful as X-rays or gamma rays strikes some physical object, some of the radiation interacts with the object.

The radiation waves miss most of the electrons in the object. A wave interacts only if there is a perfect bull's eye on an electron. This enables an X-ray or gamma ray to penetrate quite deeply into material before it hits an electron perfectly on target.

If the radiation wave hits an electron, a powerful collision occurs. The collision is so powerful that the electron is ripped free of the atom to which it was attached. The freed electron is a particle of radiation that has weight as well as energy and speeds off through the substance.

This electron has been given so much energy that the electron itself now strikes other electrons and causes them to break free from the atoms to which they were attached. The photograph shown in Figure 2.2 illustrates what happens when a narrow beam of X-rays or gamma rays passes through air.

X-rays and gamma rays disturb the atomic structure so much that atoms may enter into chemical reactions with each other. These chemical reactions happen in a radiographer's film. Chemical reactions also can cause biological damage if the radiation's energy breaks apart molecules in the cells of the human body. The harmful effects of radiation are discussed in Chapter 4.

X-rays and gamma rays cause almost no damage in metals, however. Because metals conduct electricity easily, if an atom loses an electron, other electrons are free to move in the metal to quickly restore the electrical balance. No chemical reaction occurs to damage the material.

Ionization

Ripping the electron off an atom is called *ionization*. Ionization means that two ions (or electrically charged particles) have been created. The electron has a negative electrical charge. The atom that remains behind has a positive electrical charge. A radiation survey meter responds to charged particles or ions that are created inside its detector.

So far we have talked about ionization caused by wavelike radiation such as X-rays and gamma rays, but ionization can be caused by particles of radiation, too. When an X-ray or gamma ray strikes an electron it gives energy to the electron. That electron is now an energetic particle of radiation. The electron causes additional ionization along its path because it hits other electrons like one billiard ball hitting another. Figure 2.2 shows the paths that the fast electrons followed.

The different types of radiation, waves or particles and ionizing or non-ionizing, are shown in Figure 2.3. In the remainder of this manual, when we say *radiation* we will mean *ionizing radiation*. The term *radiation* will include gamma rays and X-rays, but not visible light or microwaves.

Radiation Quantities and Units[14]

Radiation is measured by the International System of Units (SI). SI units include the becquerel, coulomb, sievert and gray. The literature for radiation safety also uses older units, such as roentgen, curie, rad and rem. Because of the widespread use of the older units in the United States (Figure 2.4), especially in regulatory documents dealing with health and safety, the United States Department of Commerce in 1998 accepted these older units with SI. All these units are discussed briefly below.

Disintegration Rate

Disintegration rate is the rate at which a radionuclide decays. In SI, the unit for radioactivity is the *becquerel* (Bq), one disintegration per second. Because billions of disintegrations are required in a useful source, the prefix *giga-* (10^9) is used and the unit is normally seen as *gigabecquerel* (GBq). An older unit is the *curie* (Ci), simply the radiation of 1 g of radium. A curie is equivalent to 37 GBq, that is 3.7×10^{10} disintegrations per second.

Exposure

Exposure is a measure of X–radiation or gamma radiation based on the ionization produced in air by X-rays or gamma rays. The unit for quantity of electric charge is the *coulomb* (C), where 1 C = 1 A × 1 s. The original *roentgen* (R) was the quantity of radiation that would ionize 1 cm^3 of air to 1 electrostatic unit (ESU) of charge (where 1 ESU = 3.3356×10^{-10} C) of either sign. A roentgen is equivalent to 258 microcoulombs per kilogram of air (1 R = 258 µC/kg of air). This corresponds to 1.61×10^{15} ion pairs per 1 kg of air, which has then absorbed 8.8 mJ (0.88 rad, where *rad* is the old unit for *radiation absorbed dose,* not the SI symbol for radian).

Absorbed Dose

Absorbed dose is the mean energy imparted to matter by ionizing radiation per unit mass of irradiated materials at the place of interest. The roentgen (R) was an intensity unit but was not representative of the dose absorbed by material in the radiation field. The *radiation absorbed dose* (rad) was first created to measure this value and was based on the *erg,* the energy unit from the old centimeter-gram-second (CGS) system. In the SI system, the unit for radiation absorbed dose is the *gray* (Gy). The gray is useful because it applies to doses absorbed by matter at a particular location. It is expressed in energy units per mass of matter or in joules per kilogram (J/kg). The mass is that of the absorbing body. One gray equals 100 rad equals 10 000 ergs per gram (1 Gy = 100 rad = 10 000 erg/g).

Dose Equivalent

Dose equivalent H is a quantity used for radiation protection that expresses on a common scale for all irradiation incurred by exposed persons. The SI unit of dose equivalent is the *sievert* (Sv), equal to 100 rem (1 Sv = 100 rem). The SI system's unit for the dose absorbed by the human body (formerly *rem* for *roentgen equivalent man;* also known as *ambient dose equivalent, directional dose equivalent, dose equivalent, equivalent dose* and *personal dose equivalent*) is similar to the gray but includes quality factors dependent on the type of radiation. This absorbed dose has been given the name sievert but its dimensions are the same as the gray (J/kg), that is, 1 Sv =1 J/kg.

Quality Factor

Quality factor is a modifying factor used in determining the dose equivalent. The quality factor corrects for the dependence of biological factors on the energy and type of the radiation. A formerly commonly used term, *relative biological effect,* is restricted in use to radiobiology. For practical purposes, the quality factors in Table 2.1 are conservative. For example, consider an absorbed dose in the lens of the eye of 1 mGy (0.1 rad) from 2 MeV neutrons. The dose equivalent is:

$$H = \begin{bmatrix}\text{Dose in} \\ \text{milligray}\end{bmatrix} \times \begin{bmatrix}\text{Quality} \\ \text{factor}\end{bmatrix}$$
$$= 1\ \text{mGy} \times 10$$
$$= 10\ \text{mSv}$$

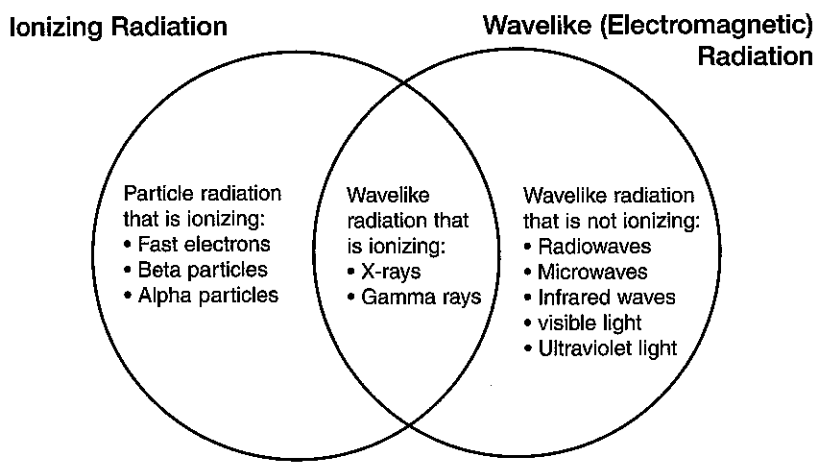


Figure 2.3: When most people talk about radiation, they are talking about ionizing radiation, shown in the left circle. Ionizing radiation can be either ionizing radiation (like fast electrons and beta particles) or waves of pure fast-moving particles (like fast electrons and beta particles) or waves of pure energy (such as gamma rays and X-rays). Wavelike radiation is shown in the right circle. Some wavelike radiation, such as visible light, does not have enough energy to produce ions. Other wavelike radiation, such as gamma rays and X-rays, has enough energy to create ions.

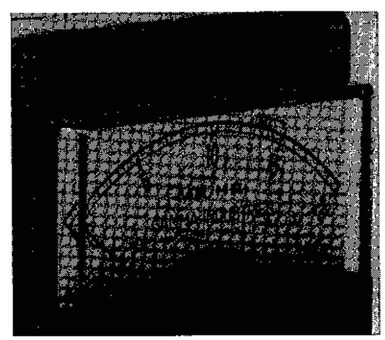


Figure 2.4: Radiation survey meters show a rate. Usually the meter will show milliroentgens per hour.

Table 2.1: Radiation weighting factors.[14]

Radiation Type	Quality Factor[a]
X-rays	1
Gamma rays	1
Beta rays	1
Neutrons	2 to 11[b]
Neutrons of unknown energy	10
High energy protons	10
Alpha particles	20
Multiple charged particles	20
Fission fragments	20
Heavy particles of unknown charge	20

a. Value of quality factor at point where dose equivalent is maximum in 300 mm (12 in.) diameter cylinder tissue equivalent phantom.

b. Quality factor depends on energy of neutron.

Compound Units[14]

The roentgen per hour (R/h) was used to designate the exposure to an ionizing radiation of the stated value. The SI unit used for this exposure rate is the *sievert* (Sv), which is 100 times as large as the compound unit it replaces: 1 Sv/h = 100 R/h. The radiation received from 1 R/h appeared equal to about 1 rem, so the relationship is approximated as 1 R/h = 0.01 Gy/h = 10 mGy/h.

A previously popular unit, roentgen per curie per hour at 1 meter (R/Ci/h at 1 m), is expressed in SI units as millisievert per gigabecquerel per hour at 1 meter (mSv/GBq/h at 1 m), such that 1 mSv/GBq/h at 1 m = 3.7 R/Ci/h at 1 m. In this relationship, roentgen converts to millisievert on a one-to-ten basis.

Exposure charts were often made by using curie minutes at a squared distance from source to sensor in inches. This was written Ci/min/in.^{2}. Exposure charts made in SI use gigabecquerel minutes for a squared distance from source to sensor in centimeters, where 1 Ci/min/in.^{2} = 50 GBq/min/cm^2.

Permissible Doses[14]

ALARA (As Low As Reasonably Achievable)

Radiographers should make every reasonable effort to maintain radiation exposures as low as is reasonably achievable. In this sense, the term *permissible dose* is an administrative term mainly for planning purposes.

Prospective Annual Limit for Occupationally Exposed Personnel

The maximum permissible prospective dose equivalent for whole body irradiation is 50 mSv (5 rem) in any 1 year.

Permissible Levels of Radiation in Unrestricted Areas

All personnel in unrestricted areas shall not receive more than 20 µSv (2 mrem) in any hour or 1.0 mSv (0.1 rem) to the whole body in any period of one calendar year.

Restricted Areas

Restricted area means an area, access to which is limited by the licensee or registrant for the purpose of protecting individuals against undue risks from exposure to sources of radiation. Restricted area does not include areas used as residential quarters, but separate rooms in a residential building may be set apart as a restricted area. The industrial radiography industry continues to delineate that area adjacent to the unrestricted area as the *restricted area* for the purposes of posting and control.

Exposure of Minors

A person under the age of 18 must not be exposed to more than 10% of the annual limits for industrial radiographers or 10% of 50 mSv (5 rem) per calendar year to the whole body or 0.5 Sv (50 rem) to the extremities.

Exposure of Females

During the entire 9 months of gestation the maximum permissible dose equivalent to the fetus from occupational exposure to the woman should not exceed 5 mSv (0.5 rem) evenly distributed over the entire pregnancy.

How Much Radiation Are People Exposed To?

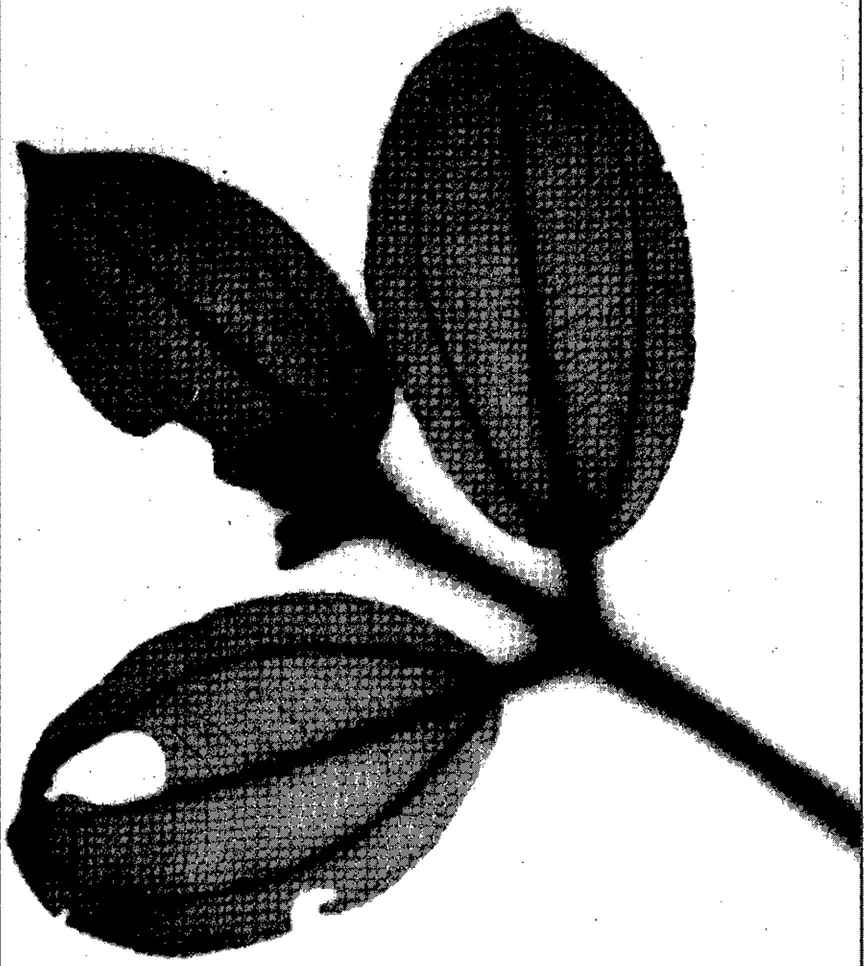
Natural Sources of Radiation

Radiation is given off constantly by naturally occurring radioactive materials all around us — in the ground, in the walls of buildings and even in our bodies. This is called *natural background radiation*. These radioactive materials have been present on Earth since it was formed. The Earth is also bombarded by *cosmic radiation*, radiation from the sun and from other sources in outer space. Roughly equal amounts of radiation come from cosmic radiation, naturally occurring radioactive materials in the human body and naturally occurring radioactive materials found in the Earth. Some radiation also comes from naturally occurring radioactive materials in bricks and concrete used in buildings. Figure 2.5 shows there is enough naturally occurring radiation in plants can show up on film

The exact amount of radiation that a person receives from natural sources depends on where the person lives. People living at high altitudes receive more cosmic radiation than people living near sea level because there is less air above them to shield them from the radiation. Also, some ground areas contain higher concentrations of radioactive materials than others. For example, in Denver, which has a high altitude and an abundance of radioactive materials in the ground, background radiation levels are about 50% higher than the United States average.

In some parts of the world, such as certain regions of India and Brazil, there are much higher levels of radiation.[3] Radiation from thorium bearing sands in these areas causes some people in these areas to receive natural radiation doses of 10 to 30 mSv (1000 to 3000 mrem) per year.

Figure 2.5: Autoradiography (self picture taking) is the radiography of an object where the radioactivity in the object itself is used to expose the film. The naturally occurring radioactivity contained in the leaves of this plant was used to make the autoradiograph.



Radiation from Manufactured Sources

People are also exposed to manufactured sources of radiation such as medical and dental X–rays, radioactive materials injected into the body for medical diagnosis or treatment, consumer products (such as color television sets, computer monitors, smoke detectors, luminous dial wrist watches and clocks, uranium contained in false teeth), fallout from nuclear weapons tests, materials released by nuclear power plants and occupational exposure of workers who work with radiation.

As can be seen from Figure 2.6, people get most of their exposure to manufactured radiation from medical and dental X-rays. The average annual dose to a person in the United States from medical and dental use of radiation is 0.9 mSv (90 mrem).[4,5] All other manufactured sources of radiation combined add about 60 μSv (6 mrem) to the average person's dose.[5,7] To make a simple approximation it can be said that the average person in the United States receives a radiation dose of about 1.0 mSv (100 mrem) per year from manufactured sources, most of which comes from medical X–rays.

So, in round numbers, the average person in the United States receives an annual radiation dose of about 2.0 mSv (200 mrem)

Figure 2.6: Average annual radiation doses from manufactured sources in the United States.

	Source	Annual Dose (mrem/y)	(mSv/y)
	Medical (primarily from diagnostic X-rays)	90	0.9
	Fallout from atomic bombs	5	0.05
	Nuclear power	0.3	0.003
	Consumer products	1	0.01
	Total	Roughly 100 mrem/y	1 mSv/y

per year, half from natural background radiation and half from manufactured sources.

Occupational Radiation Doses

Radiation is used in various occupations. Examples are medicine, industrial radiography and the operation and maintenance of nuclear power plants.

There are close to 1.5 million workers in the United States who work with or near radiation sources in some way, although most of these workers have little contact with the radiation sources and receive little or no measurable radiation dose.

The amount of radiation that a radiographer is permitted to receive by law is discussed in Chapter 8. But to simplify the legal dose limits, we can say that basically the dose limit for workers is 50 mSv (5.0 rem) per year.

By comparison, following are some average radiation doses for certain workers who received a measured dose.[8]

The average occupational dose to workers at gamma radiography companies is about 4.4 mSv/year (440 mrem/year). (The average dose includes the dose of everyone who wore a dosimeter to measure radiation dose and for whom some dose was measured.) To this we must add 2.0 mSv/year (200 mrem/year) to account for natural background radiation and radiation from other manufactured sources.[9] The total is roughly 6.0 mSv/year (600 mrem/year), about three times the average dose for the whole United States, but slightly less than the average dose for workers with measurable radiation doses at nuclear power plants. An airline pilot who flew 3000 miles per day would receive a radiation dose from cosmic rays equal to the average dose to a worker at a radiography company.

The average occupational dose of 4.4 mSv/year (440 mrem/year) at radiography companies, however, includes radiographers who perform other types of nondestructive testing and spend very little time doing radiography. The average dose also includes many people who work for companies holding a radiography license and who wear film badges but seldom or never work with radiation sources.[10]

The average dose received by a gamma radiographer who works actively is probably closer to 13 mSv (1300 mrem),[8] and annual doses of 50 mSv (5000 mrem) occur sometimes. Probably about 3000 to 4000 radiographers in the country receive doses exceeding 10 mSv (1.0 rem = 1000 mrem) per year.[11] This number is out of perhaps (very roughly) 10 000 people who spend at least a week per year actually performing radiography using radioactive materials.[12] In Chapter 4 on the effects of radiation, we will assume that the average annual radiation dose received by a radiographer is 10 mSv (1.0 rem). This is a rough estimate, but it is adequate for our purposes.

The dose that an industrial radiographer can expect to receive in a lifetime of work in industrial radiography is probably in the vicinity of 200 mSv (20 rem) according to information from the Nuclear Regulatory Commission, based on termination reports filed by licensees.[13] We will use this 200 mSv (20 rem) estimate of lifetime dose in Chapter 4 where we will discuss the risk industrial radiographers face from exposure to radiation.

Questions

1. What is *radiation*?

2. A radiation survey meter reads 100 μSv/h (10 mR/h). How long will it take before a dose of 20 μSv (2 mrem) is delivered?

3. The radiation dose rate at a certain distance from a radioactive source is 20 mSv/h (2 R/h). How long will it take before a dose of 1.0 mSv (100 mrem) is delivered?

4. Describe where naturally occurring background radiation comes from.

5. What are some factors that will affect the amount of natural background radiation an average person will receive?

6. What is the largest source of manufactured radiation that an average person is exposed to?

7. Roughly what radiation dose does an average person receive each year from natural background radiation?

8. Roughly what radiation dose does an average person receive from manufactured sources of radiation each year?

9. Roughly what radiation dose does a person working actively in gamma radiography receive at work each year?

10. What dose did your radiation badge read last month? At that rate, how much dose would you get in a year?

Chapter 3

What Is Radioactivity?

Radioactivity

Radioactivity is the emission of radiation from an unstable atom. Most atoms are stable and will never emit any radiation, but certain kinds of atoms have a large surplus of energy. These are called *unstable atoms*. Eventually unstable atoms will emit radiation — a highly concentrated form of energy. The radiation will carry off the surplus energy from the atom. The radiation can be in the form of particles that have weight, such as electrons, or in the form of weightless waves of pure energy, such as gamma rays.

The atoms of radioactive materials emit radiation when they break up. The *gamma rays* used in radiography are emitted from radioactive atoms. The atoms also emit particles called *beta particles*, fast moving electrons (Figure 3.1). Beta particles cannot penetrate the steel capsule that contains the radioactive material.

Most chemical elements have both stable and unstable forms called *isotopes*. A *stable* isotope does not emit radiation. An *unstable* isotope does. These unstable isotopes are called *radioactive isotopes* or *radioisotopes*. The radioactive isotopes used most often in gamma radiography are iridium-192 and cobalt-60.

X-ray Machines

An X-ray machine is not radioactive. Its radiation does not come from unstable atoms, but from collisions between speeding electrons and atoms. An electrical voltage causes electrons to jump across a gap and strike atoms in a target. The atoms absorb energy from the electrons and emit their surplus energy in the form of X–rays.

When the electrical voltage in an X-ray machine is turned off, no more electrons jump across the gap and radiation is no longer emitted. But radioactive atoms cannot be turned off. Nothing can be done to stop the individual atoms in a radioactive material from breaking up or to change the pace. The special requirements to store radiography sources securely are very important because no one can *turn off* radioactive atoms.

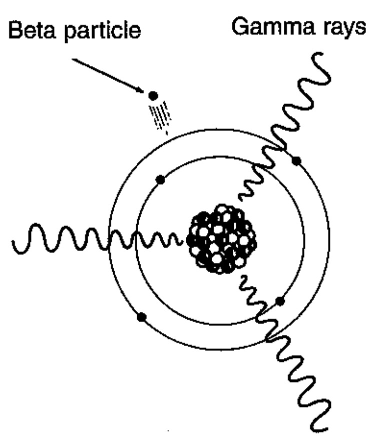


Figure 3.1: Radioactive decay. An artist's concept of an unstable atom emitting radiation. The wavy lines represent gamma rays. The black ball speeding away from the atom is a beta particle. A beta particle is a fast moving electron emitted from an atom during radioactive decay.

Radioactive Decay

The disintegration or breaking up of an unstable atom with the emission of radiation is called *radioactive decay*. Most types of unstable atoms, including those most commonly used in radiography sources, emit radiation or decay only once. Once one of these atoms has given up its excess energy, it becomes a stable atom and is no longer radioactive. This is why radiography sources become weaker and weaker. As the number of unstable atoms keeps getting smaller and smaller, less and less radiation is emitted. Eventually there will be none left and the material will no longer be radioactive.

The loss of all radioactivity can take a very long time. Even radiography sources that have become too weak to be useful in radiography are still dangerous for many years and must be handled carefully. They can be disposed of only as radioactive waste, which must be sent to special sites permitted to receive radioactive waste. Old radiography sources are usually returned to the supplier of the sources.

The strength of a source is called the *activity*. Activity is defined as the number of radioactive atoms that will decay and emit radiation in 1 second of time. In SI, the unit for radioactivity is the *becquerel* (Bq), one disintegration per second. Because billions of disintegrations are required in a useful source, the prefix *giga-* (10^9) is used and the unit is normally seen as *gigabecquerel* (GBq). The previous unit, the curie (abbreviated Ci), is equivalent to 37 GBq, that is 3.7×10^{10} disintegrations per second.

An iridium source with a strength of 3.7 TBq (100 Ci) might be used. A 3.7 TBq (100 Ci) iridium source will emit the same amount of radiation as two 1.85 TBq (50 Ci) iridium sources or 10 0.37 TBq (10 Ci) sources. (An *iridium source* refers to iridium–192, a *cobalt source* refers to cobalt–60.)

A 37 GBq (1 Ci) iridium source does *not* give the same radiation dose as a 37 GBq (1 Ci) cobalt source. The iridium source and the cobalt source both have exactly the same number of disintegrations per second and a disintegration of each produces about two gamma rays.[1] The average energy of a gamma ray from cobalt is about two and one half times as great as the average energy of gamma rays from iridium. Because of this, the dose rate around the cobalt source will be greater than the dose around the iridium source.

The greater energy of the cobalt gamma rays means that its rays will be more penetrating. Cobalt requires more shielding and can be used to radiograph thicker sections of metal than iridium.

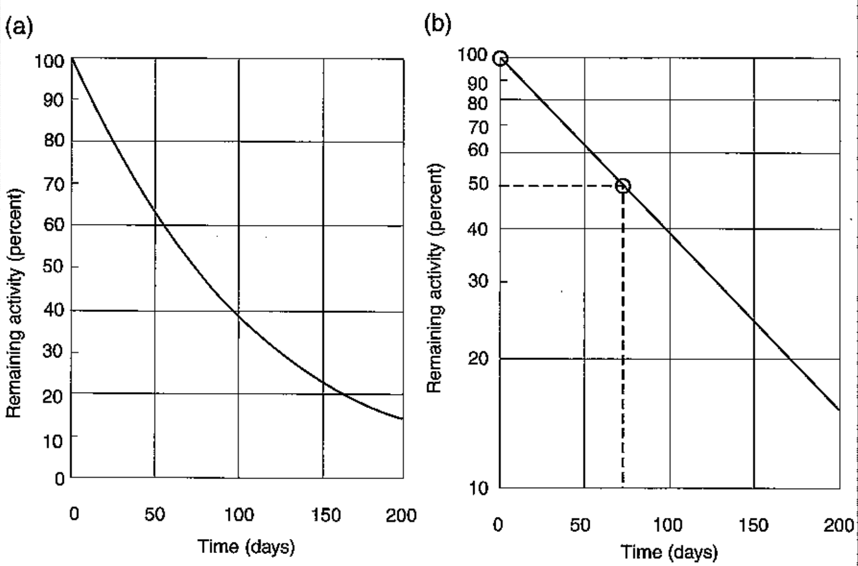
Half Life

The time required for one half of the unstable atoms of a radioactive isotope to decay is known as the *half life* and is given the scientific symbol $T_{1/2}$. One of the unique characteristics of each kind of radioactive isotope, such as iridium-192 or cobalt-60, is its half life. The half life of an isotope cannot be changed.

If the number of radioactive atoms in a source is reduced by half, the amount of radiation emitted by the source will also be reduced by half. After 1 half life, the activity of a radioactive source will be one half its initial activity. After two half lives, the activity will be reduced to one quarter of its original activity ($1/2 \times 1/2 = 1/4$). Similarly, after three half lives, only one eighth of the original activity will be left ($1/2 \times 1/2 \times 1/2 = 1/8$), and so on. After ten half lives, less than one thousandth of the original activity will remain.

The illustration in Figure 3.2a shows how fast a 3.7 TBq (100 Ci) iridium-192 source decays. Iridium has a half life of almost 75 days (or about 2.5 months). At the end of 75 days, half of the original 3.7 TBq (100 Ci) of iridium has decayed away, leaving 1.85 TBq (50 Ci). At the end of a second 75 days, an additional 0.925 TBq (25 Ci) has decayed away.

Figure 3.2: Decay curves for iridium-192: (a) linear plot; (b) logarithmic plot.



Cobalt-60 has a half life of just over 5 years. If the initial quantity is 3.7 TBq (100 Ci), in 5 years there will be about 1.85 TBq (50 Ci). How much will there be in 10 years? In 20 years?

In 10 years, 0.925 TBq (25 Ci) of cobalt-60 will remain. Twenty years is equal to four half lives. Therefore, the activity will be 3.7 TBq (100 Ci) $\times 1/2 \times 1/2 \times 1/2 \times 1/2$. this equals

$$\frac{3.7 \text{ TBq}}{16} = 0.232 \text{ TBq}$$

$$\frac{100 \text{ Ci}}{16} = 6.25 \text{ Ci}$$

Having some idea of the rate of decay of these radioactive materials can be useful. An iridium source that was last used 2 or 3 months ago should have a radiation dose rate on the container surface of about half of what it was before.

But if the surface radiation dose rate on a cobalt-60 container reads only half of the value it had 2 or 3 months ago, something is wrong. Either the radiation survey meter is not working quite properly, or the cobalt source might have moved in its shield. The radiographer will have to check to see if the survey meter is operating properly and if the container is properly locked.

Using Graphs

The method just described can be used to make a rough approximation of how much activity a source will lose over some time interval. Sometimes such a rough approximation will be useful. However, to determine the proper exposure times for film, it is necessary to have a much more precise estimate of the activity of the radioactive source.

To provide an accurate value for source activity, the manufacturer of every radiography source provides a graph with the source. The graph gives the activity of the source at different dates.

To learn how to read these graphs, a simplified graph is first shown here (Figure 3.2b). To determine the activity of a source over a period of time, first locate number of days at the bottom of the graph. Now follow the vertical line up from that number to the diagonal line, which indicates *source activity*.

From that point, move horizontally to the left. Note where this horizontal line crosses the left hand scale of the graph. Read the source activity from the scale on the left hand side.

Look carefully at the left hand scale. Note the distance between

100% and 90%. The distance is small. It takes only a little more than a week to lose this percentage. Now note the distance between 20% and 10%. Are they the same distance apart on the graph? No, the distance is much greater. It takes many more days for a source to lose that same percentage.

The reason the distances are different is that a larger source loses activity faster than a smaller source. For example, in 1 half life of 75 days, a 3.7 TBq (100 Ci) iridium source loses 1.85 TBq (50 Ci). But a 0.74 TBq (20 Ci) source loses only 0.37 TBq (10 Ci) in 1 half life.

The 3.7 TBq (100 Ci) iridium source loses 1.85 TBq (50 Ci) of activity in its first 2.5 months. In its second 2.5 months, it loses only 0.925 TBq (25 Ci). The line showing source activity is a curved line. We got a straight line in Figure 3.2b by making the distance from 3.7 TBq (100 Ci) to 1.85 TBq (50 Ci) the same as the distance from 1.85 TBq (50 Ci) to 0.925 TBq (25 Ci) by using a different type of scale.

Logarithmic Scales

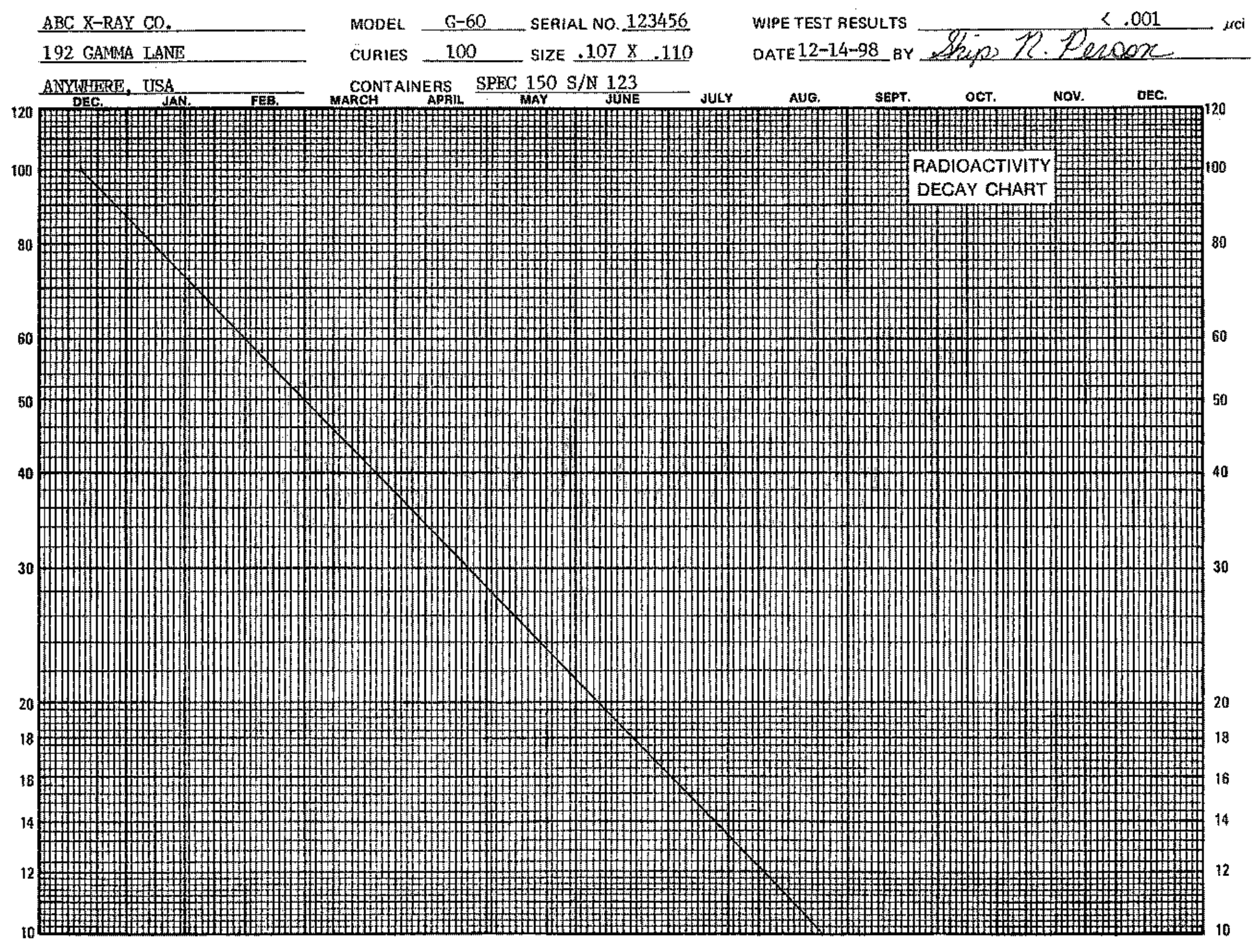
To show source activity by using a straight line, it is necessary to expand the scale on the left hand side as the source gets weaker. This is called a *logarithmic scale* or *log scale*. The graphs in Figure 3.2b and 3.3 have a logarithmic or log scale on the left and are drawn on *semilogarithmic* graph paper. The graph paper is *semi* or *part* logarithmic because the left scale is logarithmic; the bottom scale showing the date is an ordinary scale.

A radiographer must be able to read decay graphs with log scales.

Can Radiography Sources Make Things Radioactive?

A sealed radiography source will not make other things radioactive unless the source is leaking. The metal objects exposed to radiography sources will not become the least bit radioactive. After the source is removed from the area, no radioactivity will remain except when using neutron radiography, where a little radioactivity will remain. However, neutron

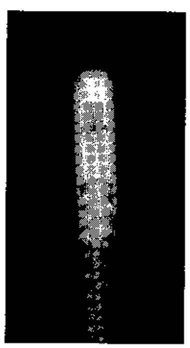
Figure 3.3: A sample logarithmic decay scale.

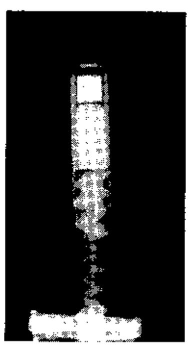


radiography is not discussed in this book. People exposed to sealed radiography sources do not become radioactive and are not a radiation hazard to others.

In radiography, the radioactive materials are sealed inside a steel capsule (shown in Figure 3.4). If the capsule were to leak or be broken open, the radioactive materials could escape from the capsule. Radioactive materials could also escape if some radioactive materials got into the weld in the source. The radioactive materials in the form of a dust could then be spread all over the radiography camera and onto anything the camera touched. The radiographer and anyone else touching the camera could get the radioactive material on their skin and clothing.

Figure 3.4: A radiograph of two radiography sources shows the radioactive material inside the steel capsules. The white squares are iridium-192. The capsules are attached to steel cables.





This spread of radioactive materials is called *radioactive contamination*. Fortunately, the spread of contamination from radiography sources is very rare. Nuclear Regulatory Commission radiography licensees report only one or two sources they suspect of leaking per year on the average.[2]

While on a person's skin, the radioactive material delivers a radiation dose to the person. The particles of radioactive material may be difficult to remove completely from the skin because particles may work themselves into the skin the same way grease gets worked into the skin of an auto mechanic.

If particles get into the air, they may be inhaled. If inhaled, some radioactive material will be deposited in the lungs and will expose the person to radiation from inside the body. The biological processes in the body would cause most of the radioactive material to be excreted (for example, through the urine), but this is a much slower process than cleaning the skin. Also, radioactive decay would cause the amount of radioactivity to gradually reduce.

In several accidents, people exposed to sealed radiation sources have been refused admittance to hospitals. The hospital workers mistakenly thought the people were radioactive and would be dangerous to others or would contaminate the hospital with radioactive material.

In July 1980, a radiographer in Pennsylvania was at first refused admission to a hospital after a traffic accident.[3] In the accident, the radiography camera was thrown from his truck into some weeds at the side of the road. The radiographer acted properly. He told the police that a radiation source was present, had them secure the area around the camera and told them to contact the company radiation safety officer. The radiation safety officer recovered the radiography camera, which was undamaged. The police apparently called the hospital to tell them that they were sending a person injured in a radiation accident. The hospital called the Nuclear Regulatory Commission and eventually, the hospital personnel were convinced that the radiographer was not radioactive.

Any radiographer who might be involved in a similar situation should be prepared to explain (1) that someone may have been exposed to radiation but that person is not contaminated with radioactive material, (2) that the person is not emitting radiation and (3) that the person is not a hazard to others.

A sealed radiography source does not make a person or anything else radioactive. The rare source that does leak can cause radioactive materials to be spread to its surroundings, although most leaking sources cause little such radioactive contamination.

Questions

1. What is *radioactivity*?
2. What is a *radioactive isotope*?
3. With respect to a radioactive source, what do the terms *becquerel* and *curie* refer to?
4. If a radiographer has three sources of 185 GBq (5 Ci), 370.37 GBq (10 Ci) and 555.55 GBq (15 Ci) activity and places them together, what is the activity of the combined source?
5. What is a *half life*?
6. If we start with a 2.96 TBq (80 Ci) source, how much activity remains after one half life? After four half lives?
7. What is *radioactive contamination*?
8. Does a gamma radiography source make radiographed objects radioactive?

Chapter 4

What Are the Harmful Effects of Radiation?

Scientists have long known that exposure to radiation can have harmful effects in humans. Some of these effects are radiation burns, cancer and genetic defects in future generations. Even death can occur soon after very large doses of radiation are received.

Scientists have known for more than 50 years that these types of health effects can result from radiation exposure. They have studied these effects in people who have been exposed to radiation in medical treatment, in radiation accidents or as a result of exposure to atomic bomb radiation in Hiroshima and Nagasaki. Scientists have also studied the effects of radiation on animals that were exposed to radiation in experiments.

Radiation burns were first noted in 1896 within a month of Roentgen's announcement of the discovery of X-rays.[1] Within a year or two it was widely known that X-ray workers had to take some precautions to avoid injury. Some of the early X-ray workers took the warnings seriously and protected themselves. Others, although warned, did not take precautions. A combination of optimism and enthusiasm over an exciting new discovery seems to have led them to abandon all caution.[1] These people suffered serious radiation burns. In fact, by about 1905, the dangers from exposure to radiation were well enough understood and believed that the chronic radiation injuries seen among the earlier workers became quite rare.

Early experimenters with natural radioactivity also suffered burns caused by radiation.[2] Henri Becquerel burned himself by carrying a sample of radium in his pocket. Both Marie and Pierre Curie received radiation burns on their skin from working with radium.

By 1905, it was known that excessive exposure to radiation could cause cancer. Large repeated doses of radiation to the hands of workers frequently caused fatal skin cancer, as shown in Figure 4.1. Many of the early medical radiologists died of this type of skin cancer. Some suffered over 100 amputations each in an effort to stop the progress of the cancers in their bodies.[1] Pieces of the affected part of their bodies were amputated, often starting with the fingers, one joint at a time. In 1922 in Hamburg, Germany, a memorial was dedicated to 169 of these pioneer scientists who died as a result of the radiation they were exposed to during their work.[2] Marie and Pierre Curie both developed leukemia, perhaps from exposure to radiation.[2]

By the late 1920s, scientists knew that radiation caused genetic defects in the offspring of insects that had been exposed to radiation. The scientist who discovered this, Hermann Muller, won the Nobel Prize in 1946.

Prompt Effects of Radiation

Very large doses of radiation can cause harmful health effects within hours or weeks. Such effects are called *prompt effects* because they appear fairly soon after exposure. The prompt effects are radiation burns to exposed skin and radiation sickness, which can be fatal.

Other radiation effects occur years after exposure. These are

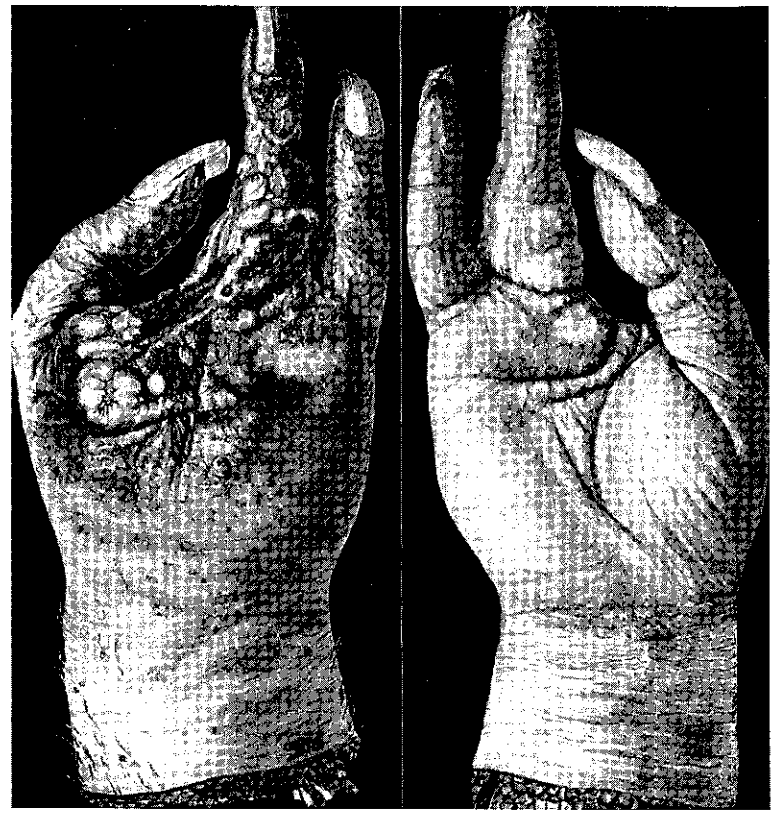


Figure 4.1: Two views of the right hand of a pioneer medical radiologist. The first injury to this radiologist was seen in 1899, 3 years after the discovery of X-rays was announced. The hand was amputated in 1932 and death from cancer occurred in 1933. Cancerous conditions like this were caused by repeated doses of radiation adding up to many thousands of rem. Because early radiation workers learned of precautions that should be taken to prevent excessive exposure, the chronic irritation and fatal skin cancer shown here are no longer seen.

called *delayed effects* because they do not occur right away. Cancer and genetic defects in offspring, which occur years after exposure to radiation, are examples of delayed effects.

Prompt effects of radiation will be discussed first because of their special importance to radiographers.

Radiation Burns

Radiography accidents commonly result in high radiation doses to a small part of the body. A part of the body may receive a radiation dose great enough to cause radiation burns.[3] Most often the hands and fingers receive the burns, but occasionally other parts of the body are affected.

Burns to the hands can result when a radiographer touches or almost touches a source for just a few seconds. The *temperature* of the source is not high, but the *radiation intensity* at the surface of a radiography source is extremely high. The burns are caused by radiation, not heat, so it can't be felt.

Radiation burns, equivalent to a first degree heat burn or mild sunburn, first become evident when the dose to a portion of the body exceeds about 6 Sv (600 rem) at one time. The person receiving the burns may feel a sensation of warmth or itching within a few hours after being exposed to the radiation. An initial reddening or inflammation of the affected area usually appears several hours after exposure to the radiation and fades after a few more hours or days. The reddening may reappear as late as two to three weeks after the exposure. A dry scaling or peeling of the irradiated portion of the skin is likely to follow. Medical attention should be sought; but aside from avoiding further injury and guarding against infection, medical treatment is not required. Recovery should be fairly complete.

If a radiographer has been performing radiography, an unexplained reddening of the skin may or may not be a sign that a serious radiation overexposure was received. This condition should be brought to the attention of the radiation safety officer unless the radiographer is fairly certain that the reddening is from other causes.

If a dose of 6 Sv (600 rem) is delivered to the eye within a day or two, damage to the eye can occur. At this dose, the lens of the eye starts to become cloudy, a condition called a *cataract*. Fortunately, there are no reported instances of cataracts ever having been caused by a radiography source.

If a part of the body receives a dose over 10 Sv (1000 rem) at one time, serious tissue damage like a second degree heat burn results. First inflammation occurs, followed by swelling and tenderness. Blisters will form within one to three weeks and will break open leaving raw, painful wounds that may become infected. Hands exposed to such a dose become stiff and finger motion is often painful. Medical attention is necessary to avoid infection and relieve pain.

If the dose is not too great, the visible damage may heal within several months or so, but some permanent damage to the tissue such as thinning of the skin, scarring of the underlying tissue, or damage to blood vessels may occur. This damage, like other scars, will make the exposed tissue more subject to injury and more tender to pressure or marked temperature change in the future.

At 20 to 30 Sv (2000 to 3000 rem), an injury resembling a scalding or chemical burn is caused. Figure 4.2 shows such burns and blisters on the hands of a radiographer burned by radiation. Intense pain and swelling occur within hours. For this type of radiation burn, medical treatment to reduce pain is urgently needed. The injury may not heal without surgical removal of exposed tissue and skin grafting to cover the wound. Damage to blood vessels also occurs, as shown in Figure 4.3.

Future medical problems with such highly exposed tissue can be expected (such as pain, low resistance to injury and reopening of the wound).

When more than 30 Sv (3000 rem) is received at one time, tissue is completely killed and must be surgically removed.

If a radiation dose of 50 to 100 Sv (5000 to 10 000 rem) is received gradually over a number of weeks or longer, a chronic irritation, inflammation, dryness and itching of the skin will result.[3] Once this condition has developed, it seldom heals completely. Periodically, open sores may erupt. The skin is half dead, half alive and its regenerative and recuperative powers are sharply reduced. Malignant skin cancer occurs in a large proportion of these cases.

Severe Radiation Burn

A very serious radiation burn from a radiography source occurred in California in 1979.[4-6] The burn was caused when a man found a 1.04 TBq (28 Ci) iridium radiography source that had been accidentally left at a jobsite by a radiographer. The man was not a radiographer and did not know what the source was. He picked it up, put it in his back pocket and left it there for about 45 min. The circumstances leading to the source being left at the jobsite are discussed in Chapter 11.

The radiation dose to some of the man's right buttock exceeded 200 Sv (20 000 rem).[6] At a depth of about 7.6 cm (3 in.), the dose exceeded 10 Sv (1000 rem). Much of the burned tissue had to be removed by surgery.

The man became nauseated about an hour after the exposure.

Nausea is a common symptom after the stomach receives a dose of radiation exceeding about 1 Sv (100 rem). In this case, the source was carried close enough to the stomach to cause it to receive a dose of roughly 1 to 2 Sv (100 to 200 rem). About 6 hours after exposure, the man noticed a burning feeling and a reddening of his buttock. The burning and reddening got worse and 2 days after the exposure, the man went to a doctor.

In the first few days after exposure, radiation burns are hard to recognize because they are so much like other skin irritations. The doctor thought the injury was caused by an insect bite.

The burn worsened until it became a large, open sore. The patient was hospitalized 17 days after the exposure. After 3 days of persistent questioning by the attending doctors, the man told about having the radiography source in his pocket. At this point the doctors realized that he had a radiation burn.

By this time, the man had an open wound about 10.16 cm (4 in.) in diameter and almost 2.5 cm (1 in.) deep. A second, but less severely burned area, was nearby. The wound caused continuous severe pain.

To treat the burn, doctors surgically removed the dead tissue. A thick piece of skin was cut loose from the man's thigh, folded over and sewn onto the wound to close it. Six months after the accident, the skin flap had an edge that was not healing and a nearby burned area was deteriorating. Ten months after the accident, a second skin flap was sewn onto the smaller wound. At 19 months after the accident, doctors have not yet been completely successful in closing the wounds. Further reconstructive surgery was anticipated. Two years after the accident, the man still walked with a limp and experienced pain where he was burned.

Other Examples

A similar accident happened in 1968 in India.[7] A man found a radioactive source and put it in his back pocket. He suffered a serious radiation burn as a result. Years later, a large scar remained. An even worse accident happened in Argentina, where a man found a source and put it in his front pocket.[8] Unfortunately, this placed the source closer to the arteries that carry blood to the legs. The arteries disintegrated because of radiation damage and both legs had to be amputated.

Dropped radiography sources have also been picked up by workers in Germany (1968), Japan (1971) and South Africa (1977), resulting in serious radiation burns.

Fortunately, such severe radiation burns are rare. Companies licensed by the Nuclear Regulatory Commission reported visible radiation burns

Figure 4.2: Radiation burns on hands. Twenty-four days after the accident, blisters are breaking and dead skin is sloughing off, exposing raw skin. In this case, amputation of the fingers was finally necessary.

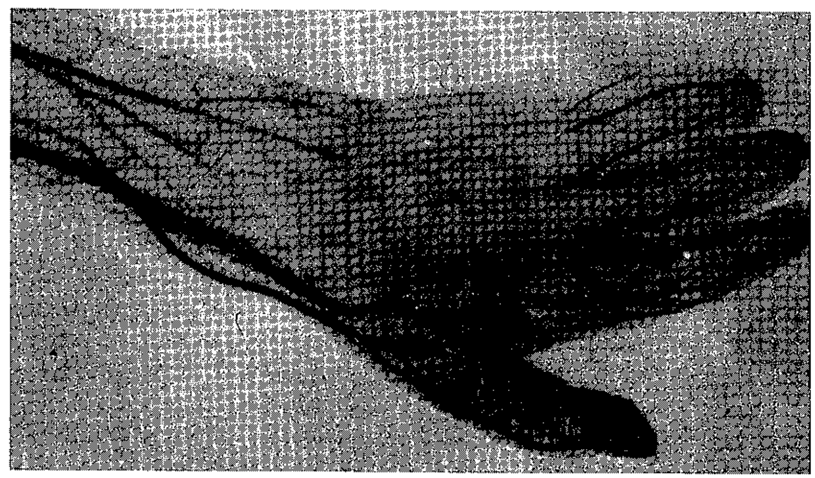


Figure 4.3: Radiation burns severely damage blood vessels. The X-ray above was taken after a dye was injected in the blood to give contrast to the picture. Circulation has been lost, as shown on the top of this photograph. The hand is that of an Algerian boy who picked up an iridium-192 source that fell from a truck.

less than once a year between 1971 and 1980 (Appendix D, Table 2). Because about two thirds of the companies performing gamma radiography in the United States are licensed by the states, not the NRC, their statistics are not included in NRC totals.

Radiographers can prevent such accidents by keeping radiography sources under their control. By not using survey meters, radiographers can lose control of their sources and fail in their responsibility to protect themselves and others.

Radiation Sickness

If a large dose of radiation is delivered to just one part of the body, like a hand, there would be localized burns, but the person would survive. However, if a large dose of radiation is delivered to the torso of the body in a short period of time, severe illness or even death can occur within a few days or weeks.[9,10]

A dose of 1 Sv (100 rem) or less delivered to the torso usually will not produce noticeable symptoms of illness. As the dose increases, symptoms of radiation sickness, such as nausea, vomiting and perhaps diarrhea occur within a few hours after the exposure. Two or three weeks later, other symptoms may appear, such as hair loss, appetite loss, general weakness, a feeling of ill health, purple spots on the skin from internal bleeding, fever and continuing diarrhea.

If the entire body is exposed to a radiation dose exceeding 5 Sv (500 rem) in a day or less, death is likely within a few weeks because the bone marrow, which produces the blood cells, can no longer produce enough cells. Below about 5 Sv (500 rem), recovery is likely with medical care although the exposed person can expect to suffer several months of illness. If the radiation dose delivered to a person is spread over several weeks, a person may survive doses as large as 10 Sv or 20 Sv (1000 rem or 2000 rem).

Deaths from a Radiography Source

Only one radiographer in the world is known to have died from the prompt effects of radiation and, in that case (July 1981), the exposure was probably not accidental. No member of the American public is known to have died from the prompt effects of radiation caused by a radiography source. However, in Mexico, China[11] and Algeria[12] people have died from large radiation exposures from radiography sources that were not properly kept in their shielded storage containers.

In a well known accident in Mexico, several people died of radiation sickness caused by a radiography source.[13]

On March 21, 1962, a construction watchman was given a 185 GBq (5 Ci) cobalt-60 source for safekeeping by his employer.[14] The watchman did not know what the source was, but he assumed it was valuable because the employer told him to store it in a safe place and to make sure no one went near it. Because the watchman knew that valuable property should be guarded carefully, he took the source home with him. The source was in a lead container, but presumably the watchman removed the source from the container out of curiosity to see what was valuable about it.

Sometime between March 21 and April 1, his son found the source and placed it in a front pocket of his trousers. On April 1, the watchman's wife found the source and placed it in a drawer in the kitchen.

On April 17, the watchman's mother-in-law came to live with the family to help care for the boy who by that time was sick from the radiation. At this time she noticed the blackening of the glasses that had been close to the source in the drawer.

On April 29 the boy died of radiation sickness. On July 19 his mother died, too. It was later estimated that the boy had received a dose between 30 and 50 Sv (3000 and 5000 rem) and his mother a dose between 20 and 30 Sv (2000 and 3000 rem).

On July 22, 1962, the employer came to the house, claimed the source and took it away. The family did not suspect the tragedy it had caused. In August, the watchman's 2.5 year old daughter became very ill. On August 13, an alert physician suspected for the first time that the common symptoms of the members of this family might be because of radiation. On August 18, the little girl died. It was later estimated that she had received between 14 and 19 Sv (1400 and 1900 rem).

On August 20, the watchman and his mother-in-law were admitted to the hospital with what appeared to be radiation exposure symptoms. Because he was away from the house a lot, the watchman had been exposed on and off and it is believed that he had received less exposure than the other members of the family. He was discharged from the hospital on September 6, but kept under close medical observation. His mother-in-law did not survive. She died on October 15. It was estimated that she received between 15 and 30 Sv (1500 and 3000 rem) over the period of time she was exposed.

This tragedy could have been avoided if the radiography company had kept better control of its sources. A radiography source must not be left in the hands of anyone who does not know how dangerous it is.

Delayed Effects of Radiation

Fortunately, exposure to doses of radiation large enough to cause radiation burns or radiation sickness are very rare. As stated earlier, in the United States visible radiation burns happen in the radiography industry only about once or twice a year on average. The low doses of radiation that most radiographers receive have no such dramatic effects, but may have effects that take many years to appear. Low doses of radiation may cause cancer and may cause genetic defects in the children of exposed people. It has not been shown scientifically that these effects result from radiation doses within legal limits, but agencies that regulate radiation exposure assume that low doses of radiation can have such effects.

Cancer

Most scientists accept the possibility that exposure to radiation, no matter how little, may have some risk of cancer associated with it. However, most exposed people will have no ill effects from the radiation they receive. About one fifth of the United States population will die of cancer.[24] A few of these cancers might be caused by radiation, but scientists believe that most cancers have other causes. If a person does get cancer, it is impossible to know whether the cancer was caused by exposure to radiation or whether the cancer would have occurred anyway from some other cause. *Cancer caused by radiation cannot be distinguished from cancer from other causes.*

Scientists do not yet know exactly how cancer is caused in humans. But it appears that most cancers are caused by some sort of a defect or damage to the deoxyribonucleic acid (DNA) molecules that control how the cells divide to make more cells (Figures 4.4 and 4.5). However, scientists do not yet understand exactly how the DNA molecules are damaged.

The DNA contained in each cell of the human body contains the *instructions* or *blueprints* for building an entire person. A complete human being develops from one single cell. The DNA makes a copy of itself and the cell with two sets of DNA divides into two separate cells. This is how a human is formed from a single cell, how children grow bigger and how new cells are formed to heal scratches and cuts on the skin.

Scientists believe that cancer occurs when something goes wrong with the way the DNA reproduces itself and creates new cells. Cancer is the uncontrolled growth of cells which eventually crowd out and kill other cells needed in the body.

The exact mechanism by which ionizing radiation or chemicals causes cancer is not known, but scientists can see that radiation damages the cell's essential DNA (Figure 4.6). And scientists accept as a prudent assumption the possibility that even low doses of radiation may increase a person's chance of getting cancer. The lower the dose, the less the assumed risk.

Figure 4.4: The DNA molecule, which forms the basis for all life on Earth, is a large molecule with the shape of two spirals twisting around each other, much like the banisters of a spiral staircase. Each of the balls in the picture above represents an atom of some element such as carbon, oxygen or hydrogen. Cancer is believed to be caused by damage to DNA that starts to malfunction.

A radiographer will be exposed to some radiation. There may be a risk of cancer because of that exposure. The important question is, how large is the risk of cancer because of radiation exposure?

How Large Is the Cancer Risk?

No one knows exactly what the chances are of dying of cancer because of a radiation dose, but

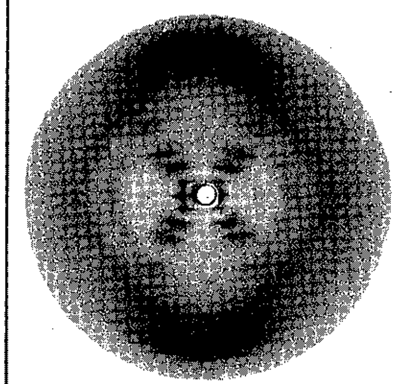


Figure 4.5: A radiograph revealed the structure of DNA to scientists, thereby telling them how living cells can reproduce copies of themselves. The radiograph shown above is different from normal radiographs. A normal radiograph is made by X-rays or gamma rays that pass directly through the material being examined. This radiograph was made in 1951 by the X-rays that were scattered or reflected out of a narrow X-ray beam by the DNA. The diagonally placed spots indicate the spiral structure as shown in Figure 4.4.

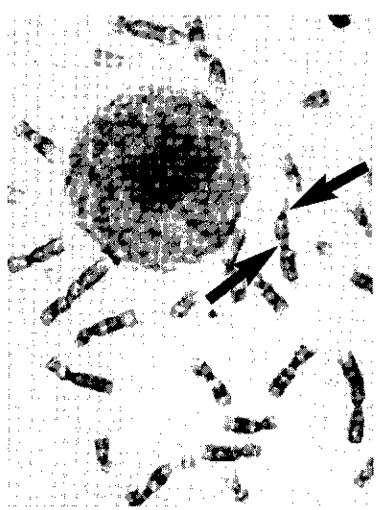


Figure 4.6: Scientists can see the damage that radiation causes by using microscopes. The large ball is an intact human cell. The small pieces are chromosomes, made by DNA, from a cell that has been chemically broken apart. One of the chromosomes is abnormal. It has two indentations because of two chromosomes fused together. Radiation can cause this to happen. By counting the number of such abnormalities in a blood sample, scientists can estimate the dose that the person received.

there are good estimates of the upper limit of the cancer risk. In fact, the estimates of cancer risk because of radiation exposure are probably more reliable than the estimates of cancer risk from any other hazardous material. This is because radiation has been studied more than any other hazardous material.

In the United States, one person in five dies of cancer. Most scientists would agree that for every 10 mSv (1 rem) of radiation that a person receives, the chance of dying from cancer is increased by no more than one chance in 10 000. This means that each rem received during a lifetime adds one chance in 10 000 of dying of cancer.

We must distinguish between the risk of *getting* cancer and the risk of *dying* of cancer. Of those who get cancer, roughly half die from the disease. In this chapter we discuss the risk of dying from cancer. For every person who dies from a radiation caused cancer, one other person would get a radiation caused cancer, but would not die as a result of that cancer.

In Chapter 2, we estimated that about 10 000 people are regularly engaged in taking radiographs in the United States. On the average, these actively working radiographers receive a dose of about 10 mSv (1 rem) per year, as noted near the end of Chapter 2. If we add up the radiation dose to all of these workers, they would receive about 100 Sv (10 000 rem) per year. This means that cancer caused by the radiation dose to all radiographers in 1 year might claim the life of one radiographer.

Reports filed with the Nuclear Regulatory Commission show that workers who spend their lifetimes working as radiographers can expect to receive lifetime doses, on the average, of about 200 mSv (20 rem) (see Chapter 2). A dose to each worker of 200 mSv (20 rem) might result in up to 20 cancer deaths per 10 000 workers. Remember that 200 mSv (20 rem) is the *average* lifetime dose for radiographers. Some get more. If a worker receives a lifetime dose of 1 Sv (100 rem), the worker's chance of dying of radiation caused cancer might rise to one chance in 100 or 1%. This 1% would be added to the 20% chance of cancer death that an average American faces.

Another way of comparing a radiographer's risk from radiation to the risks in other industries is to compare days of life lost. Scientists have calculated that 10 mSv (1 rem) of radiation may, *on the average*, result in the loss of 1 day of life expectancy.[18] So the radiation exposure expected to be received in a lifetime as a radiographer may cost, on the average, 20 days of a life. We emphasize *on the average* because most radiographers will suffer no loss of life expectancy. But the unfortunate radiographer who does get cancer will, on the average, lose perhaps 15 years of life expectancy.[19]

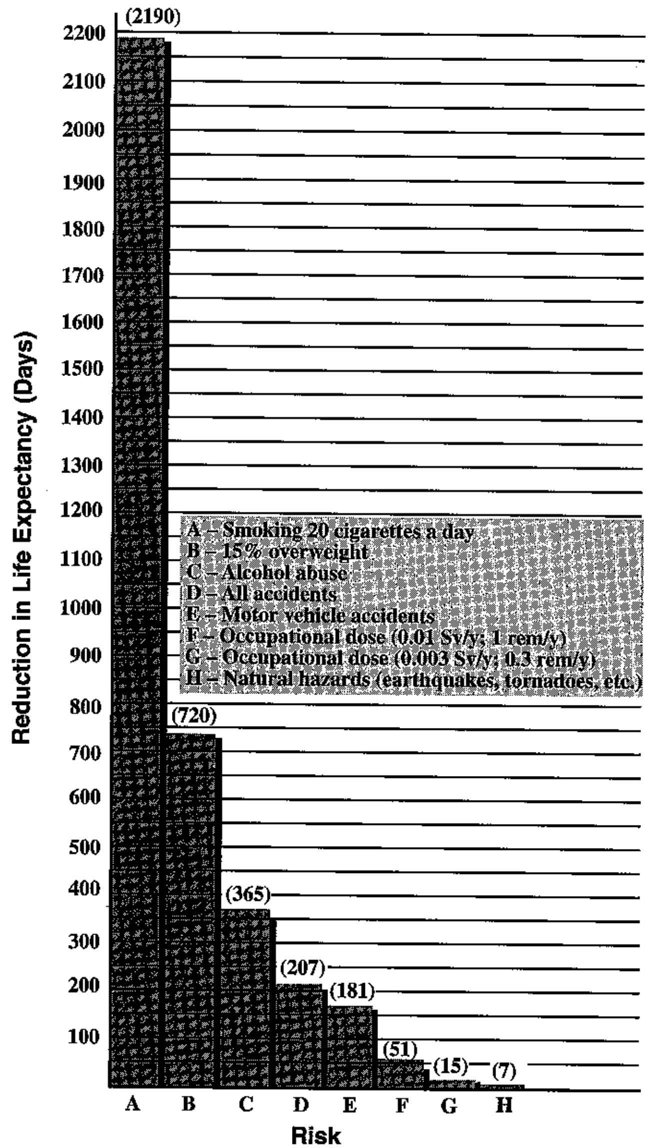
The loss of life faced by radiographers can also be compared to other risks that we face in life. Figure 4.7 shows that the risk from radiation faced by radiographers is small when compared to many other risks. Perhaps what is most striking about Figure 4.7 is the risk from smoking, which stands in a class by itself.

Another comparison of a radiographer's risks to the risks faced by other workers is a direct comparison of the number of probable cancer deaths. Unfortunately, we do not know nearly as much about the cancer risks from other things as we know about the risks from radiation. However, we do have one point for comparison. The United States Council on Environmental Quality has estimated that job related exposure to chemicals and other substances causes very roughly about 400 cancer deaths per 10 000 American workers.[21] This includes the cancer risk from such things as a lifeguard's added exposure to sunlight, a taxi driver's exposure to smog and a cabinet maker's exposure to wood dust. On this basis, the average American industrial worker faces roughly 20 times the cancer risk that the average radiographer gets from radiation. In fact, a radiographer could face more risk of cancer from chemical substances on the job than from radiation.

Genetic Defects from Radiation

Since 1927, scientists have known that radiation can cause genetic defects. Genetic defects

Figure 4.7: Estimated loss of life expectancy from risks in life compared to a radiographer's risk from radiation.



Sources: NRC Regulatory Guide 8.29, 1996, and *The World Almanac® and Book of Facts 1997.*

from radiation are caused when radiation has damaged the reproductive cells in a person and a damaged cell eventually develops into a child. The child formed thus inherits damaged or defective genes. Damage to the genes implies a defect in the blueprints to construct a complete organism from the single damaged cell. A change in the genes can also be called a *mutation of the genes.*

The early evidence that radiation causes defects was obtained from experiments with insects. Increased numbers of genetic defects were found in the descendants of insects that had been exposed to radiation though the types of genetic defects were the same types that are found naturally. Subsequent experiments with animals had similar results. Radiation increased the number of genetic defects but did not cause different types of defects than those that occur naturally. The danger of radiation exposure is that it can *increase the number* of genetic defects that do occur. Figure 4.8 shows genetic defects in the skeleton of a mouse caused by radiation.

Most people who suffer from a genetic defect do not know they have the defect because there are usually no easily detectable signs. Some genetic diseases are obvious. For example, two well known diseases caused by genetic defects, color blindness and hemophilia (a failure of the blood to clot), are readily detectable. Most other genetic diseases are not easily detectable.

Often doctors cannot say whether a person has a particular genetic defect or not. Genetic defects most often cause some cells in the body to produce some essential protein, enzyme, or hormone in reduced quantity or with reduced potency. The effect of such defects on a person is usually that the person is not quite as healthy and vigorous as normal.

Scientists believe that at least 10% of all people born have a genetic defect serious enough to cause disease or ill health during their lifetime.[22] About 1% of all people born have genetic defects severe enough to cause malformation of their bodies or serious or crippling disease. At least half of all genetic defects are probably inherited from the parents. Other defects are new and did not exist previously in either parent.

Most new genetic defects are a natural event with no outside cause. The process by which a single cell from each parent creates an entirely new human being is so complex that there are many chances for error. When the errors are large, the development of a fertilized egg into a human being usually fails. A fetus (unborn child) may abort before a woman even knows she is pregnant. About half of all spontaneously aborted fetuses have serious genetic defects.

Genetic defects that cause the most serious disorders are usually eliminated from the population within a few generations because the carriers do not survive to reproduce. On the other hand, genetic defects that cause less severe disorders will affect more people because more carriers survive to reproduce.

It is possible that a genetic change will be beneficial, but beneficial changes are rare. The human body is a very complex machine, far more complex than a jet aircraft, for example. If someone makes a random change in the aircraft's equipment, the aircraft's performance is far more likely to be harmed than improved. It is the same for humans. Scientists estimate that the chance that 10 mSv (1 rem) of radiation will cause a genetic defect in a future child of the person exposed to radiation is about one third the chance that the radiation will cause a fatal cancer in the person.[23] Previously we estimated that 10 mSv (1 rem) of radiation would result in no more than one chance in 10 000 of a cancer death. The risk of a genetic defect in a child born to a person exposed to 10 mSv (1 rem) of radiation is less than one third of a chance in 10 000 and may be 10 times smaller. Because genetic defects are less likely than cancer and because the consequences are not as great (decreased health rather than death), the risk of cancer is more significant than the risk of genetic defects.

These estimates of genetic defects caused by radiation exposure are based on experiments with insects and animals. Genetic defects that could be associated with radiation have not been observed in any group of humans. Even studies of the children of the Japanese atomic bomb survivors, thousands of whom had very large doses, did not have any more detectable genetic defects than normal.

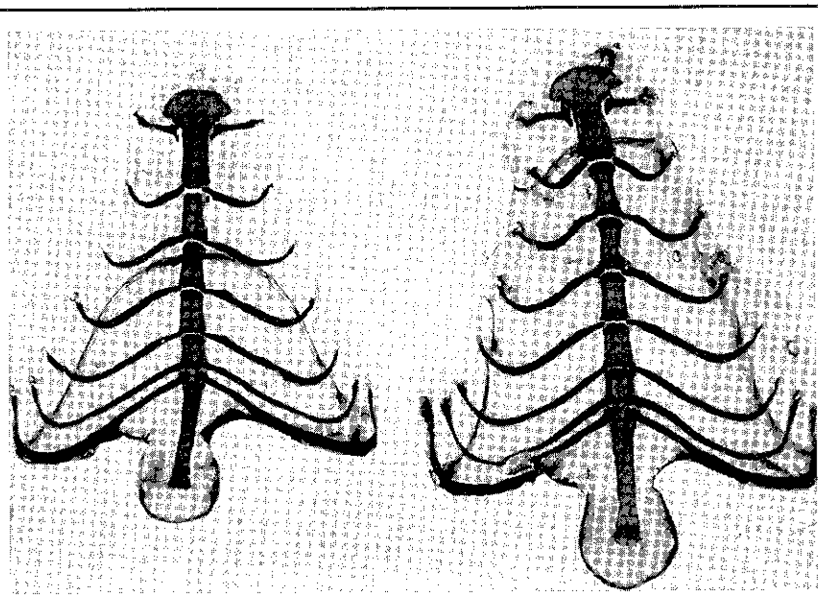


Figure 4.8: Genetic defects in the skeleton of a mouse. The bones on the left are normal. The mouse on the right has an extra piece in its breast bone and an extra set of ribs caused by a radiation induced genetic defect. Like those shown here, most genetic defects are not extremely visible.

Radiation Exposure of Pregnant Women

When a pregnant woman is exposed to radiation, there may be damage to the unborn child. The unborn child is more sensitive to radiation than an adult, especially during the first 3 months after conception. We are not talking here about genetic defects that can be passed from generation to generation. Rather we are talking about developmental defects affecting only the unborn child.

The Nuclear Regulatory Commission provides information about the biological risks to the unborn child from exposure to radiation in relation to other risks encountered during pregnancy in NRC Regulatory Guide 8.13, *Instruction Concerning Prenatal Radiation Exposure*. Every woman of childbearing age who works as a radiographer should read the instructions in this guide. The licensee is responsible for providing workers with instruction about risks associated with radiation exposure, including specific instruction about exposure risks to the unborn, before working in a restricted radiation area.

How Sure are Scientists About Delayed Effects of Radiation?

Anyone who only reads newspapers and watches television as a source of information about radiation would be likely to conclude (1) that the harmful effects of radiation were first noticed in the last few years, (2) that scientific study of the effects has been neglected in the past, (3) that radiation produces more horrible effects than other hazardous materials and (4) that there is enormous uncertainty in the effects of low doses of radiation. All four of these impressions are incorrect. This chapter has already discussed how the first three of these impressions are wrong. This section will cover the uncertainty in our knowledge of radiation doses below legal limits.

Scientists working on determining radiation effects will indeed say that their estimates of the effects of low doses of radiation are uncertain. That means that the effects of doses of radiation below legal limits are *too small* to be measured directly.

Why can't the effects be measured directly? One reason is that cancers caused by radiation cannot be distinguished from cancers resulting from other causes. The variability of the cancer death rate attributable to sex, age, lifestyle, race and unknown factors adds uncertainty to any estimate of the expected number of cancer deaths in a particular group of people.

In 1977, statistics showed that out of 10 000 people who died, about 2000 of them died of cancer. But in any group of 10 000 people selected, the number dying of cancer could be considerably more or less than 2000.

For example, in the United States, the cancer death rate for men in the 1980s was 50% higher than the rate for women. In 1930, women had a higher rate, but their rate has dropped.

Sometimes the reasons for these different death rates are partially understood, for example, the effect of cigarette smoking on lung cancer. But often the reasons for the differences are not well understood, making it difficult to compare the differences in cancer death rates between people exposed to radiation and people not exposed to radiation.

If 10 000 people are each exposed to 10 mSv (1 rem) of radiation, scientists estimate at most one additional cancer death. Because so many factors affect the cancer death rate, it is not possible to measure whether the one additional cancer death occurred or not. The normal variability in the number of cancer deaths would be several hundred in a group of 10 000 people.

Even though scientists have gone to great effort to detect radiation effects, they have been unable to identify any effects from small amounts (millisieverts or rem) of radiation per year.

Therefore, we can say with certainty that additional cancer and genetic defects caused by radiation doses within legal limits are much less than the normal incidences of these effects. There is only uncertainty in precisely *how small* the effects are. This is the uncertainty scientists talk about. There is almost no uncertainty that the risks from radiation doses within the legal limits are smaller than many other risks we commonly encounter and accept in our lives.[25]

Still one might ask, "If the legal dose limits have some risk, even a small one, why not have lower limits?" A similar question could be raised about highway speed limits. When the speed limit was lowered to 55 mph, highway fatalities decreased but did not disappear. The only absolutely safe limits would be 0 mph and 0 mSv (0 rem) per year, but then we wouldn't get anywhere.

Questions

There is a risk associated with the radiation dose that will be received in work as an industrial radiographer. The following questions are intended to be discussed with the instructor and other students.

1. What other risks do you take in life?
2. How would you compare radiation risk to these other risks?
3. How do you feel about taking this risk in your job?
4. Can you accept the risk from working as an industrial radiographer?
5. What can be done to minimize risk?

True or False

1. T F It was not discovered that radiation could cause cancer until after the atomic bombs were exploded during World War II.
2. T F Touching or almost touching a radiography source for only a few seconds can cause radiation burns.
3. T F Some radiographers have had to have their fingers amputated because of injury from radiation burns.
4. T F If a radiographer acts quickly, it is okay to pick up a loose radiography source by hand and place it in the camera.
5. T F Radiation workers will develop a tolerance to radiation exposure.
6. T F Although radiography sources can cause radiation burns on the skin, the injuries from exposure to the sources are never fatal.
7. T F Redness of the affected skin is the first sign of a radiation burn.
8. T F Redness, swelling and blistering are all symptoms of radiation burns.
9. T F Everyone who receives an over exposure to radiation will eventually get cancer.
10. T F Any exposure to radiation may increase a person's risk of getting cancer.
11. T F It is usually possible to tell whether a cancer was caused by radiation or by some other cause.
12. T F Scientists know that cancer cannot be caused by radiation doses below legal dose limits.
13. T F Because of the radiation exposure they receive, radiographers are much more likely to get cancer than other people.
14. T F Compared to other jobs, radiography is quite hazardous because of the effects of radiation.
15. T F If a person receives a radiation dose of 10 mSv (1 rem), the life expectancy will be decreased by almost a year.
16. T F As a radiographer, the risk of getting cancer because of radiation exposure will be one of the larger risks faced in life.
17. T F The genetic effects of radiation are a greater health hazard than the cancer risk.
18. T F Radiation does not cause genetic defects.
19. T F Children born with genetic defects caused by radiation are easily identifiable because the defects are so grotesque.

Chapter 5

How Do Time, Distance and Shielding Affect Dose?

In the previous chapters it was noted that any exposure to radiation, even a very small dose, may have some risk. Therefore, it is important to keep the radiation dose not only below legal limits, but as far below those limits as can be reasonably achieved. In this chapter, ways to keep the radiation dose at the lowest reasonably achievable level will be discussed.

There are three basic ways to lower the dose when working with radiography sources.

1. **TIME:** Don't stay near a radiography source or camera any longer than necessary.
2. **DISTANCE:** Stay as far away from the source as possible.
3. **SHIELDING:** Use shielding between any person and the source.

Time

The *less time* spent near a radioactive source, the *less radiation dose* will be received. Dose from dose rate and time is calculated as follows.

dose = dose rate × time

So, if a survey meter reads 50 μSv/h (5 mR/h) at some location, the radiographer will receive a dose of 50 μSv (5 mrem) in 1 hour, 0.1 mSv (10 mrem) in 2 hours, 0.15 mSv (15 mrem) in 3 hours and so forth. This means the less time spent at that location, the less dose will be received.

Radiation dose is also reduced by spending as little time near a source as possible.
[*Note: Because survey meters read in CGS, not SI units, all example problems and review questions will have SI units either in parentheses or worked as a separate problem.*]

Problem 1:

The radiation survey meter reads 100 mR/h at some point. How much dose would a person receive standing at that point in (a) 1 hour, (b) 1/2 hour, (c) 6 min and (d) 1 min?

Answer:

Use the formula,

dose = dose rate × time

(a) dose = 100 mR/h × 1 h
= 100 mR or 100 mrem

(b) dose = 100 mR/h × 1/2 h
= 50 mR or 50 mrem

(c) It is first necessary to convert minutes into hours. To do this divide 6 min by 60 min/h:

$$\frac{6\ \text{min}}{60\ \text{min/h}} = 0.1\ \text{h}$$

Now:
dose = 100 mR/h × 0.1 h
= 10 mR or 10 mrem

(d) We do this problem the same as we did problem (c):

$$\frac{1\ \text{min}}{60\ \text{min/h}} = 0.0167\ \text{h}$$

dose = 100 mR/h × 0.0167 h
= 1.67 mR or 1.67 mrem

Problem 1 in SI:

The radiation survey meter reads 1 mSv/h at some point. How much dose would a person receive standing at that point in (a) 1 hour, (b) 1/2 hour, (c) 6 min and (d) 1 min?

Answer in SI:

Use the formula,

dose = dose rate × time

(a) dose = 1 mSv/h × 1 h
= 1 mSv

(b) dose = 1 mSv/h × 1/2 h
= 0.5 mSv

(c) It is first necessary to convert minutes into hours. To do this divide 6 min by 60 min/h:

$$\frac{6\ \text{min}}{60\ \text{min/h}} = 0.1\ \text{h}$$

Now:
dose = 1 mSv/h × 0.1 h
= 0.1 mSv

(d) We do this problem the same as we did problem (c):

$$\frac{1\ \text{min}}{60\ \text{min/h}} = 0.0167\ \text{h}$$

dose = 1 mSvh × 0.0167 h
= 0.0167 mSv

Calculations such as these can be used to establish boundaries for the restricted area and high radiation area.

Problem 2:

The radiographer plans to take four exposures at a field location. He estimates that the four exposures can be completed in less than 1 hour. Each exposure will take 3 min. From past measurements it is known that at 30.48 m (100 ft) from the source the dose rate will be 20 mR/h. How much dose will a person standing 30.48 m (100 ft) from the source will receive in any 1 hour?

Answer:

$$\frac{3\ \text{min}}{60\ \text{min/h}} = 0.05\ \text{h}$$

20 mR/h × 4 exposures × 0.05 h
= 4 mR or 4 mrem

So, a person standing at 30.48 m (100 ft) from the source during the hour would receive a dose of 4 mrem.

Problem 2 in SI:

The radiographer plans to take four exposures at a field location. He estimates that the four exposures can be completed in less than 1 hour. Each exposure will take 3 min. From past measurements it is known that at

30.48 m (100 ft) from the source the dose rate will be 20 mR/h. How much dose will a person standing 30.48 m (100 ft) from the source will receive in any 1 hour?

Answer in SI:

$$\frac{3\,\text{min}}{60\,\text{min}/\text{h}} = 0.05\ \text{h}$$

$$200\ \mu\text{Sv/h} \times 4\ \text{exposures} \times 0.05\ \text{h} = 40\ \mu\text{Sv}$$

So, a person standing at 30.48 m (100 ft) from the source during the hour would receive a dose of 40 µSv.

Calculations like this are needed to establish safe working distances.

Distance

Increasing the distance from a source will *decrease* the amount of radiation received. As radiation travels away from the source it spreads out and becomes less intense. This idea is illustrated in Table 5.1. More radiation will strike a person nearer the source.

Radiation spreads out in straight lines as it moves away from the source. In Figure 5.1, the same rays of radiation that pass through the small opening, pass through the middle squares and also the largest squares.

Moving from the opening to the middle squares, the distance from the source is doubled, but the area that the radiation spreads into is four times as great. The area of the opening is 6.45 cm² (1 in.²). The area of the middle squares is 25.8 cm² (4 in.²). Therefore, if we double the distance from the source, the radiation intensity is only one quarter as great. Its intensity is divided by four because the same number of rays is spread out over an area four times as large as before.

Moving from the opening to a square four times as far away, the radiation would be spread out over an area of 103.2 cm² (16 in.²).

If the distance is two times as great, the intensity is divided by four (2 × 2 = 4). If the distance is three times as great, the radiation intensity is divided by nine

Table 5.1: Dose rate versus distance using a 3 TBq (81 mCi) iridium-192 source.

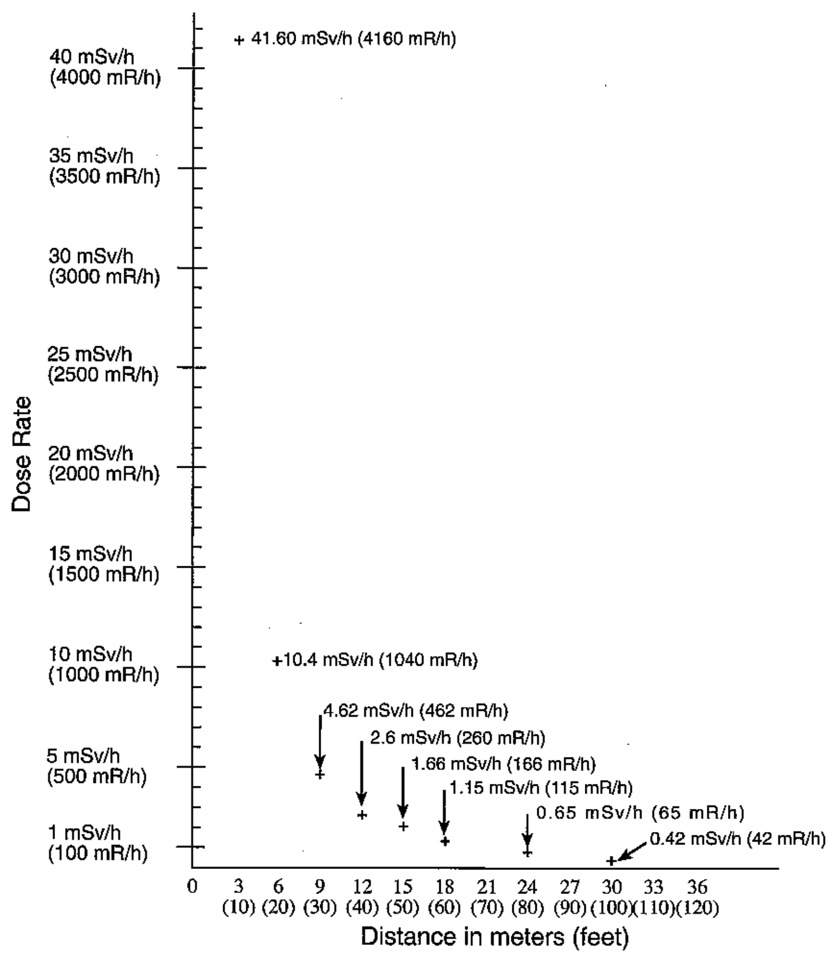
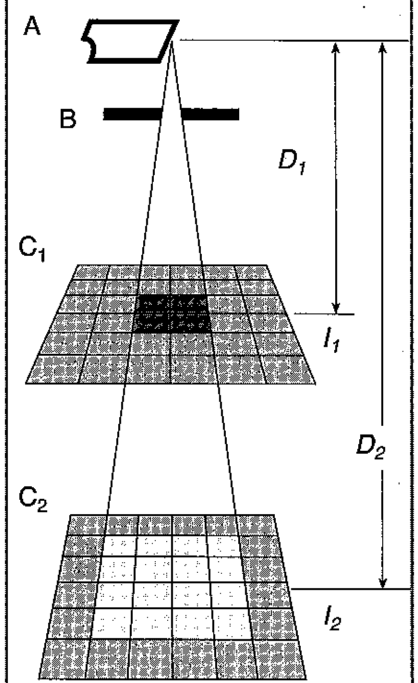


Figure 5.1: Inverse square law formula.



Legend

A = radiation source
B = focal point
C_1 = first film plane
C_2 = second film plane
D_1 = source-to-film distance at first film plane
D_2 = source-to-film distance at second film plane
I_1 = intensity at distance D_1
I_2 = intensity at distance D_2

(3 × 3 = 9). If the distance is four times as great, the radiation intensity is divided by 16 (4 × 4 = 16).

The Inverse Square Law

An equation can be written that will indicate the dose rate at any distance from a source if the dose rate at some other distance is known.

This exposure versus distance ratio can be calculated using the inverse square law.

$$\frac{I_1}{I_2} = \frac{(D_2)^2}{(D_1)^2} \text{ or } I_2 = I_1 \frac{(D_1)^2}{(D_2)^2}$$

where:

- I_1 = intensity at closest distance (D_1)
- I_2 = radiation intensity at farthest distance (D_2)
- D_1= distance at intensity I_1
- D_2= distance at intensity I_2

In order to use this formula easily, memorize the constants shown in Table 5.2 and use a calculator. (Use a calculator with x^2 and square root functions). When using the inverse square law, always be sure to use the same values. For example, if the distance value of D_2 is in meters, then the value of D_1 must also be expressed in meters. In addition, if I_1 is expressed in sieverts per hour, then I_2 must be expressed the same way.

Table 5.2: Constant intensities for iridium-192 and cobalt-60

Type of material	Specific gamma constant intensity per Ci at 0.3 m (1 ft)	Specific gamma constant intensity per 3.7 TBq at 0.3 m (1 ft)
Iridium-192	5.2 R/h	0.052 Sv/h
Cobalt-60	14.0 R/h	0.14 Sv/h

Problem 1:

When performing radiography using an 80 Ci iridium-192 source that is unshielded, with a 25 ft set of controls, what is the dose rate at the end of the controls? (See Table 5.2. for more information.)

Answer:

The first step in solving a problem of this magnitude is to write down the formula and determine the facts that are already known. In this problem, I_1 is 5.2 R/h (constant) × 80 Ci or 416 R/h, D_2 = 25 ft, and D_1 is 1 ft. The formula now looks like this

$$\frac{416}{I_2} = \frac{(25\text{ ft})^2}{(1\text{ ft})^2}$$

The next step is to work the formula by first squaring 1 ft and 25 ft. This is accomplished by multiplying them by themselves. 1 × 1 = 1 and 25 × 25 = 625. Now cross-multiply and divide the formula to solve for I_2.

416 × 1 ÷ 625 =
0.6656 R/h or 666 mR/h

Problem 1 in SI:

When performing radiography using an 3 TBq iridium-192 source that is unshielded, with a 7.6 m set of controls, what is the dose rate at the end of the controls? (See Table 5.2. for more information.)

Answer:

The first step in solving a problem of this magnitude is to write down the formula and determine the facts that are already known.

What part of 3.7 TBq is 3 TBq?

(3 ÷ 3.7) × 100 = 81

I_1 = 81 × 0.052 = 4.216 Sv/h
D_1 = 0.3 m
D_2 = 7.6 m
I_2 = ?

$$\frac{4.216}{I_2} = \frac{57.75\text{ m}^2}{0.09\text{ m}^2}$$

(4.216 Sv/h × 0.09 m^2) ÷ 57.75 m^2
= 0.00657 Sv/h
or
6.57 mSv

Problem 2:

Using the same set of circumstances as Problem 1, how far from the source would the radiation be reduced to 2 mR/h? (See Table 5.2 for more information.)

Answer:

Again, write down the formula and determine the known values. I_1 is unchanged at 416, I_2 = 2 mR/h or 0.002 R/h, and D_1 = 1 ft. After plugging in the known values, the formula looks like this

$$\frac{416}{0.002} = \frac{(D_2)^2}{1\text{ ft}}$$

Again work the formula. Square D_1 (1 × 1 = 1), cross–multiply and divide the formula to solve for D_2. Remember that to get feet, take the square root of the product.

$$416\text{ R/h} \div 0.002\text{ R/h}$$
$$= 208000\text{ ft}^2$$

Take the square root:

$$456\text{ ft} = D_2$$

Problem 2 in SI:

Using the same set of circumstances as Problem 1, how far from the source would the radiation be reduced to 0.00002 Sv (0.02 mSv)?

$$\frac{4.16}{0.00002} = \frac{(D_2)^2}{(0.3)^2}$$

$$(4.16 \text{ Sv/h} \times 0.09 \text{ m}^2) \div 0.00002 \text{ Sv/h} = (D_2)^2$$

$$18720 \text{ m}^2 = (D_2)^2$$

Take the square root

$$136.8 \text{ m} = D_2$$

Problem 3:

When using a cobalt-60 source, a survey meter measures a dose rate of 5 mR/h at 50 ft from the source. What would the distance from the source be if you want to limit exposure to 2 mR/h? (See Table 5.2 for more information.)

Answer:

Begin, as always, by writing down the formula and determining the known values. $I_1 = 2$ mR/h or 0.002 R/h, $I_2 =$ 5 mR/h or 0.005 R/h, and $D_2 = 50$.

$$\frac{0.002 \text{ R/h}}{0.005 \text{ R/h}} = \frac{(50 \text{ ft})^2}{(D_1)^2}$$

Square D_2, 50 × 50 = 2500, then cross-multiply and divide the formula to solve for D_1.

$$(0.005 \text{ R/h} \times 50 \text{ ft}^2) \div 0.002 \text{ R/h} = (D_1)^2$$

$$6250 \text{ ft}^2 = (D_1)^2$$

Remember that to get feet, take the square root of the product.

$$79 \text{ ft} = D_1$$

Problem 3 in SI:

When using a cobalt-60 source, a survey meter measures a dose rate of 0.05 mSv/h at 15 m from the source. What would be the distance from the source if you want to limit exposure to 0.02 mSv?

$$\frac{0.05}{0.02} = \frac{(D_2)^2}{(15)^2}$$

$$(0.05 \text{ mSv} \times 225 \text{ m}^2) \div 0.02 \text{ mSv} = (D_2)^2$$

$$562.5 \text{ m}^2 = (D_2)^2$$

Take the square root

$$23.72 \text{ m} = D_2$$

It is often useful to have a graph of the dose rate at various distances from a source. The dose rates at various distances from a 37 GBq (1 Ci) iridium-192 source have been plotted in Figure 5.2(a). This plot was done on ordinary graph paper. The plot is not useful for most work. For example, what is the dose rate at 61 m (200 ft)? At 3.05 m (10 ft)? The graph cannot be read accurately, but the graph does make one thing quite clear. As the source is approached, the dose rate increases rapidly.

In Figure 5.2(b) the dose rate at various distances from 37 GBq (1 Ci) iridium-192 and cobalt-60 sources is plotted. If the strength of the source is known, the graph in Figure 5.2(b) can be used to calculate the dose rate at any distance from the source.

Consider the dose rate at a distance 0.3 m (1 ft) from a 0.37 TBq (10 Ci) iridium-192 source. Locate the distance on the bottom scale, read the corresponding dose rate for a 37 GBq (1 Ci) source 5000 mR/h, and multiply that dose rate by 10 (the strength of the source in Ci). The answer is 50 000 mR/h or 50 R/h.

What is the dose rate at a distance of 15.24 m (50 ft) from a 3.7 TBq (100 Ci) cobalt-60 source?

Locate 15.24 m (50 ft) on the bottom scale. Follow the vertical line up to the cobalt-60 curve. Read across to the vertical scale. The dose rate is 6 mR/h for 37 GBq (1 Ci). Multiply by 100 to calculate the actual dose rate for the source. The answer is 600 mR/h.

Figure 5.3 demonstrates how distance can be used to reduce radiation dose.

Shielding

Another way to reduce radiation dose is to place something between any people and the source to absorb the radiation. The material placed between people and the source is called *shielding*. In general, the more dense a material is, the more effective it will be as a shield for X-rays and gamma rays.

Uranium metal is the most effective shielding material for both X-rays and gamma rays. Tungsten is also very good. Lead is good and steel is fairly good. Concrete is not as effective as these other materials, but is often used because it is comparatively inexpensive and easy to use in construction. A thick wall of concrete can be just as effective as a much thinner wall of uranium or lead.

The most practical use of shielding in radiography can be achieved by the use of collimators. *Collimators* are small pieces of lead, uranium or tungsten that surround the source to absorb radiation not directed toward the object being radiographed. Collimators are portable and can be carried into the field.

Figure 5.4 shows several collimators. Collimators are made in various sizes and shapes for different applications. These collimators can achieve dose reductions of about 20 to 10 000 times for iridium-192 and three to 10 times for cobalt-60.

Figure 5.5 shows a collimator made of lead attached directly to a camera. This arrangement avoids having an unshielded source running through the guide tube. The camera shown uses uranium to shield the source when the source is inside the camera. Uranium is weakly radioactive and this is noted on the camera labeling.

The use of a lead collimator and lead bricks in a radiography shot is shown in Figure 5.6. The collimator is about 1.27 cm (0.5 in.) thick and reduces the dose by almost 10 times for iridium-192. A 5.08 cm (2 in.) lead brick behind the film reduces the dose by about 2000 times for the radiation beam that has passed through the lead brick. Note how much more effective 5.08 cm (2 in.) of lead is in comparison to 1.27 cm (0.5 in.). Every time the beam passes through 1.27 cm (0.5 in.) of lead, it emerges only about one tenth as strong as when it entered.

Collimators, have a hole so that radiation can strike the film. Generally collimators will also

Figure 5.2: (a) Plotting the dose rate at various distances from a 37 GBq (1 Ci) iridium-192 source on ordinary graph paper, the plot is not very useful. It cannot be read accurately. Figure (b) shows how to solve this problem – logarithmic scales.

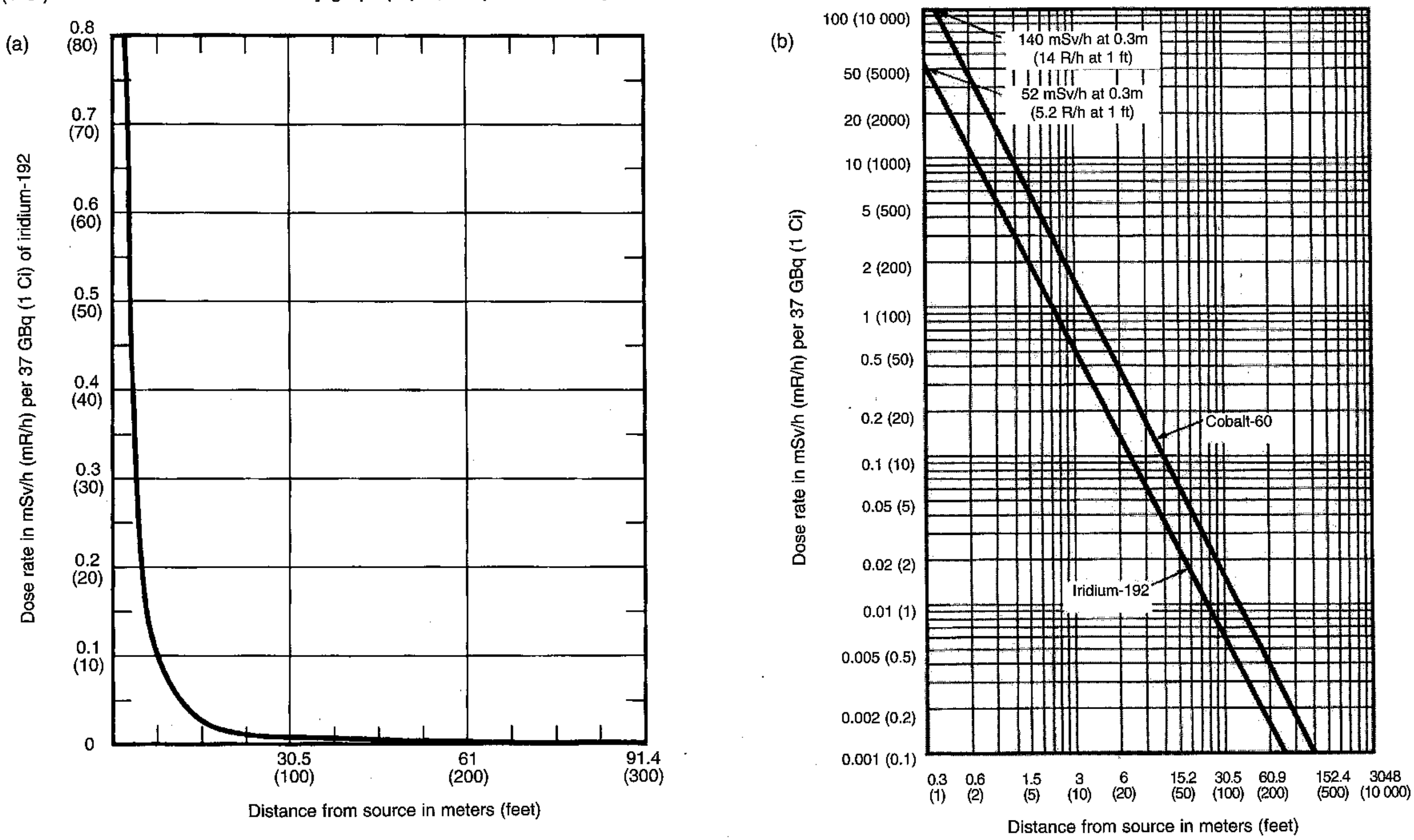
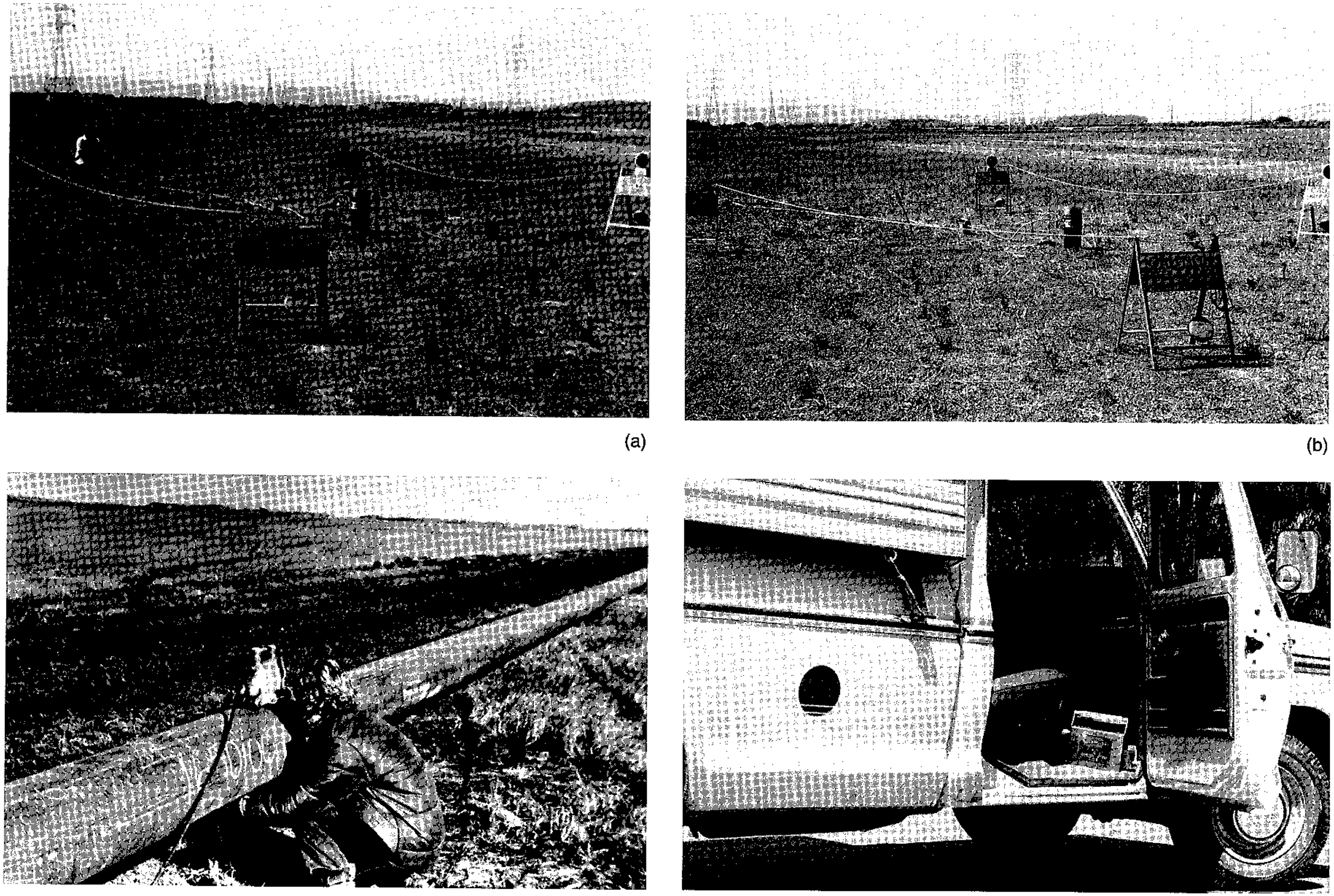
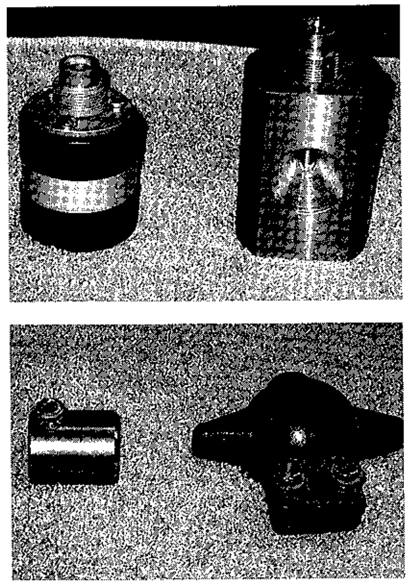


Figure 5.3: How distance can be used to reduce radiation dose. (a) Use a fairly long set of control cables. Lay the control cables out straight. (b) Walk away from the crank during the exposure. (c) Stand away from a pipeline device during exposure. (d) Don't put the camera in the passenger compartment of your truck.



(a) (b) (c) (d)

Figure 5.4: One of the most effective means to reduce the radiation dose is by using collimators such as those shown below.



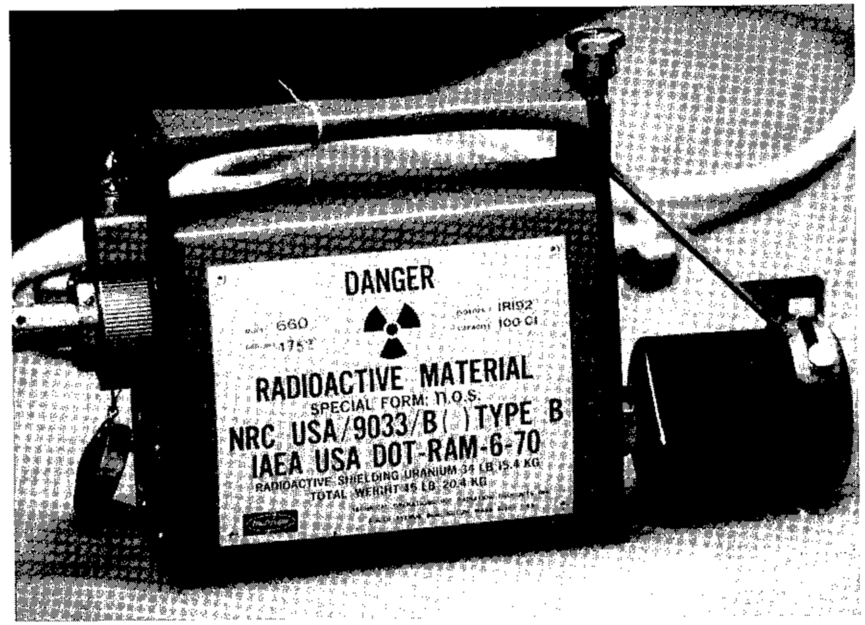


Figure 5.5: If the collimator can be attached directly to the camera (as in this picture) the source will always be at least partially shielded. The source will not travel through the unshielded guide tube.

have a second hole where the source enters. Because of this second hole, most collimators will have a second beam of radiation. The radiographer will have to consider the second beam when making radiation surveys and when setting up ropes and signs to keep people away from the radiography area.

When objects are radiographed at a permanent facility, thick concrete walls can be built around the room for shielding.

Some of the most massive shielding associated with industrial radiography is used where sources are fabricated and welded into stainless steel capsules. Figure 5.7 shows a worker using remote-controlled *master-slave* manipulators to make sources inside a massively shielded enclosure. The shielding in the walls is concrete about 1.8 m (6 ft) thick. The worker looks through leaded glass 1 m (39.37 in.) thick.

Sometimes the radiographer will want to know how much material it will take to reduce the radiation dose by one half. The thickness of a material required to reduce radiation dose by one half is called the *half-value thickness* or *half-value layer*. For example, 1.27 cm (0.5 in.) of steel will reduce the dose from an iridium source by half.

It is possible to use graphs to determine the effectiveness of different thicknesses of shielding materials. Graphs of the attenuation (reduction or weakening) of beams of gamma rays in various shielding materials are shown in Figures 5.8 through 5.12. The problems given below can be answered from these graphs.

Protective Enclosures[4]

Because of scattered radiation, protection for the operator and other personnel working nearby often requires shielding of the part being radiographed. It is preferable that the source and materials being examined should be enclosed in a room or hood with the necessary protection incorporated into the walls (Figure 5.13).

Shields can be classified as either *primary* or *secondary*. Primary shields are designed to shield against the primary radiation beam; secondary shields are just thick enough to protect against tube housing leakage and scattered radiation. For this reason, the X-ray tube or source should not be pointed toward secondary shields. Mechanical stops should be used to restrict tube housing orientations toward primary barriers. Operating restrictions, such as not pointing the beam at certain walls or the ceiling, should be spelled out in the operating procedures.

Protective materials are available in panels so that radiation barriers may be customized for work areas of various sizes. Mobile work rooms with modular designs are also available, offering the same flexibility in size and location (Figure 5.13).

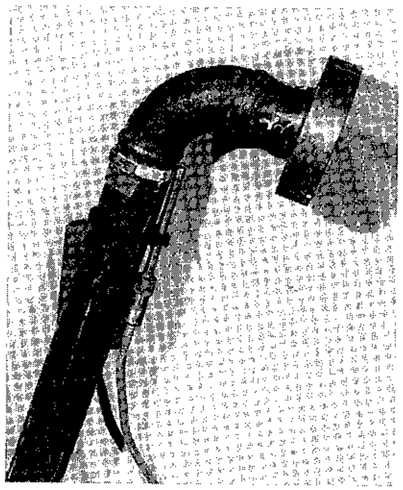
When changes in operating conditions are planned, the radiation safety officer should be contacted to determine whether additional shielding is needed.

For design purposes, the primary beam should not be pointed in the direction of high occupancy areas. Also, the distance from the radiation source to any occupied space should be as great as is practical. Scattered radiation usually has a lower effective energy than the primary beam and may be easier to shield.

Classes of Installations for X-rays and Gamma Rays[4]

There are four types of nonmedical X-ray and gamma ray

Figure 5.6: These pictures show the use of shielding to reduce radiation exposures to personnel.



(a)

(b)

(c)

(a) The snout of the guide tube is attached to the pipe to be radiographed.

(b) Lead collimator and film are attached.

(c) Lead bricks are placed over the set up. The brick behind the film is especially effective because the collimator does not provide any shielding in the forward direction.

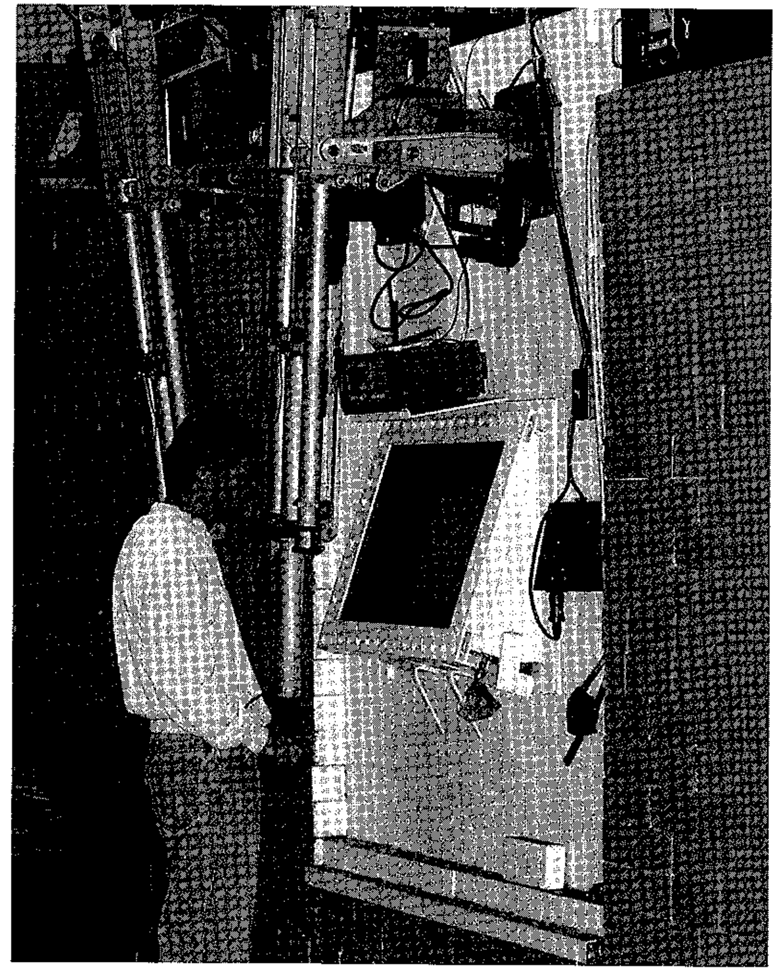


Figure 5.7: Several feet of heavy concrete shielding and glass containing lead are used to shield enclosures where radiography sources are manufactured. The operator uses master-slave manipulators to weld together the steel capsule containing the radioactive material.

installations: protective, enclosed, unattended and open.

Protective Installation

This class provides the highest degree of safety because the protection does not depend on compliance with any operating limitations. The requirements include the following.

1. Source and exposed objects are in a permanent enclosure. No one is permitted in the enclosure during irradiation.

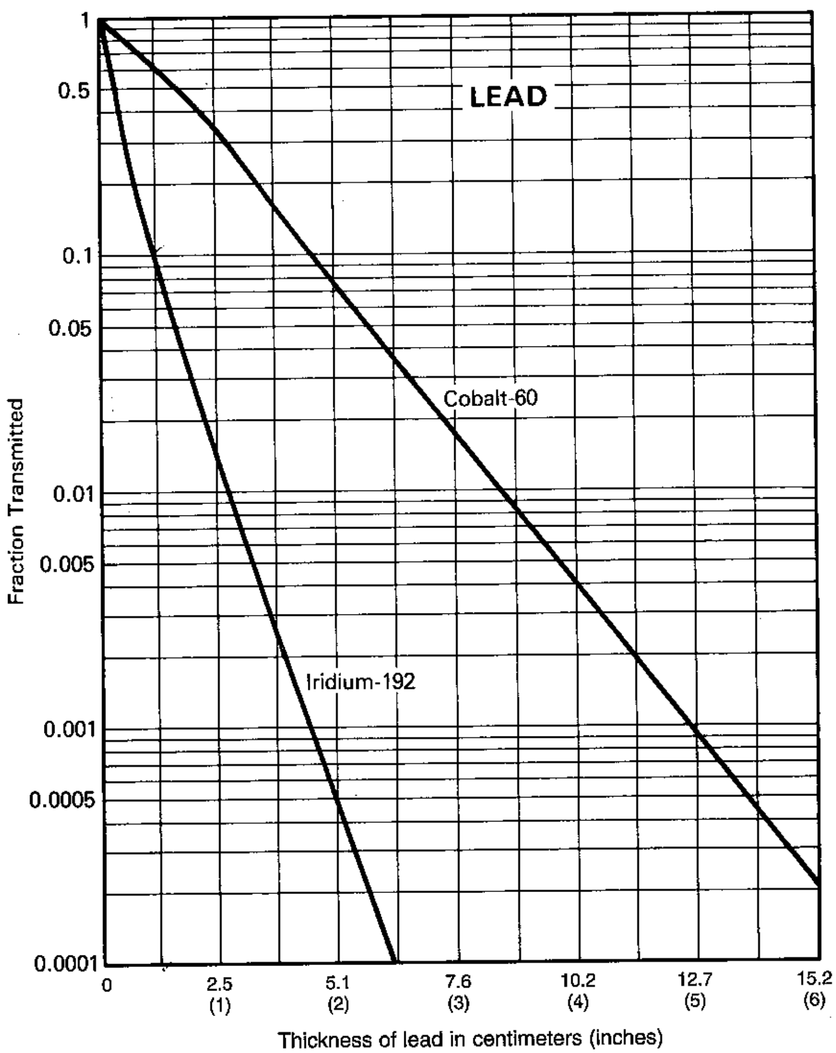


Figure 5.8: Attenuation of gamma rays in lead.

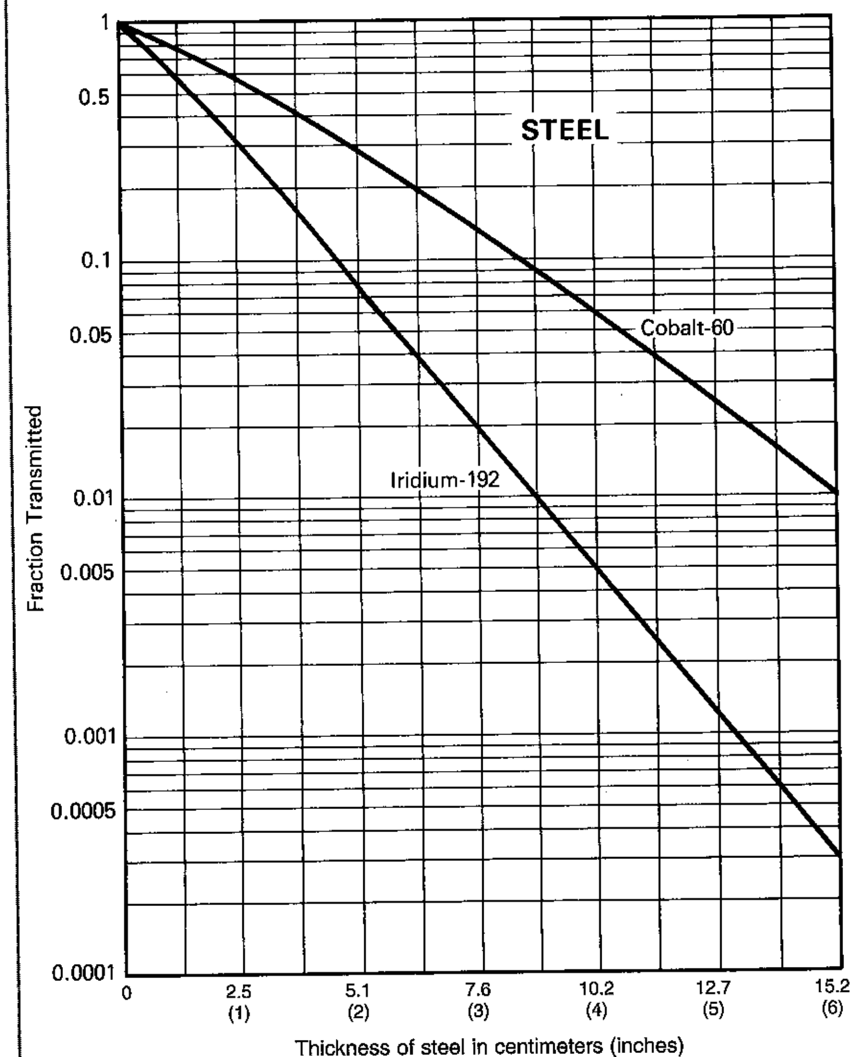


Figure 5.9: Attenuation of gamma rays in steel.

2. Safety interlocks prevent access to the enclosure during irradiation.
3. If occupancy cannot be easily determined by the operator, the following requirements should also be provided:
(a) fail safe audible or visible warning signals to indicate the source is about to be used;
(b) emergency exits;
(c) effective means of terminating the exposure from inside the enclosure (sometimes called *scramming*).
4. The radiation exposure at a distance of 50 mm (2.0 in.) outside the surface of the enclosure cannot exceed 5 μSv (0.5 mR) in any 1 hour.

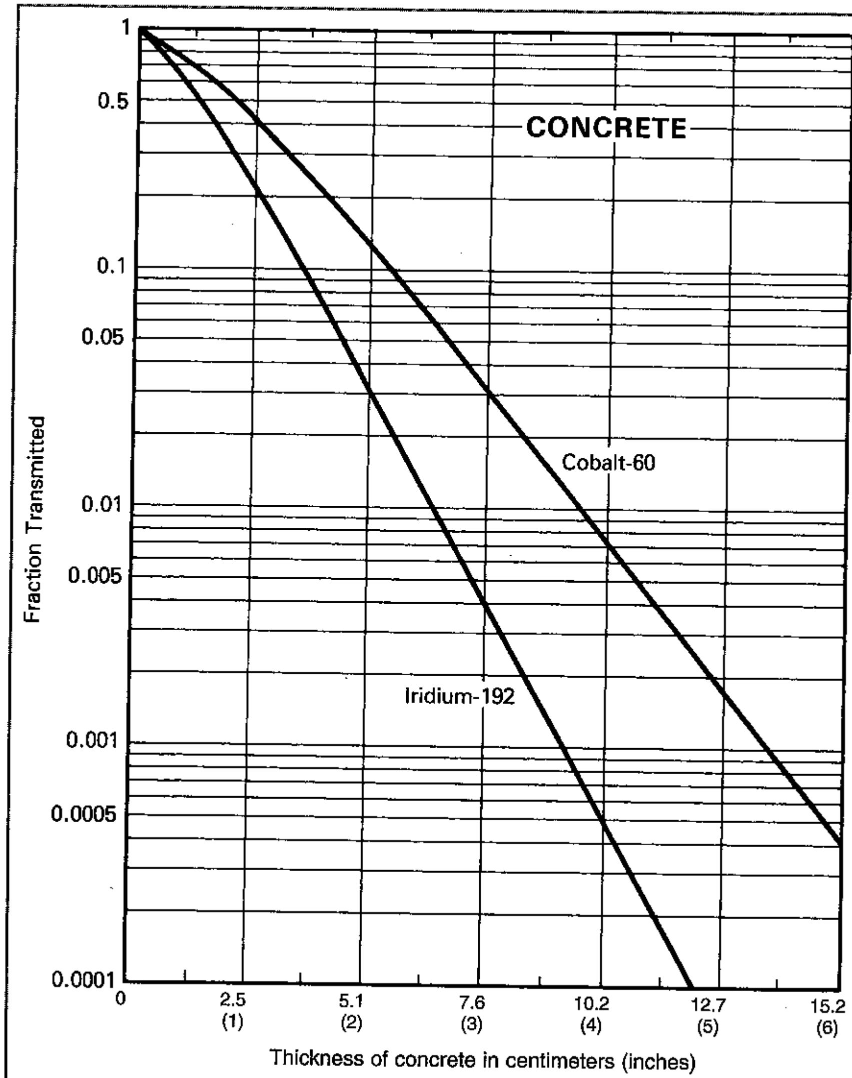


Figure 5.10: Attenuation of gamma rays in concrete.

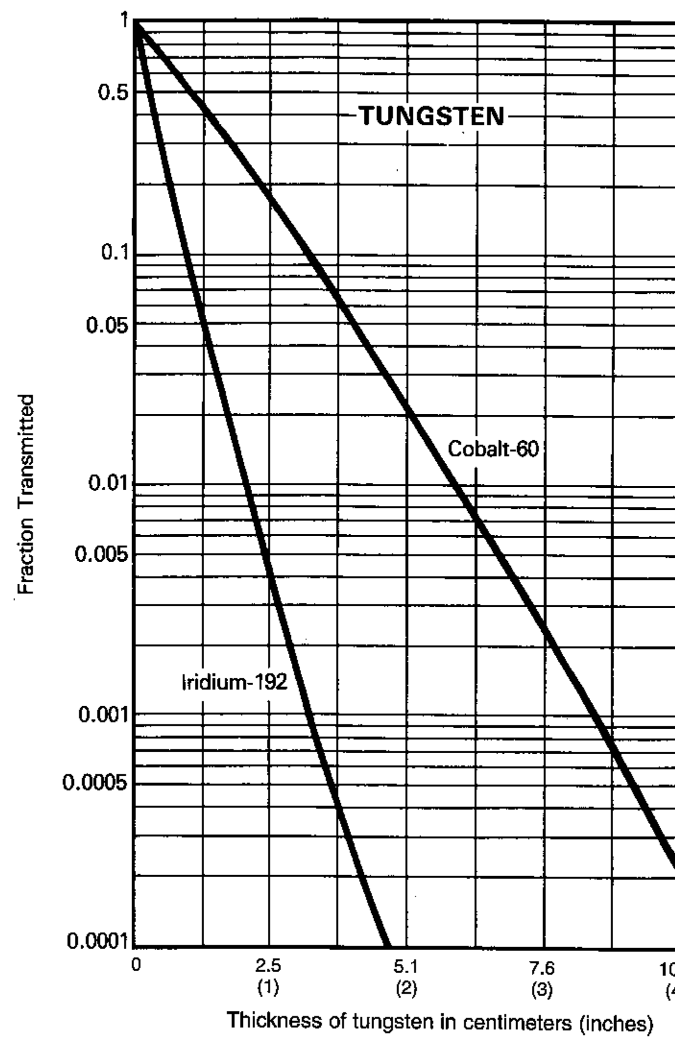


Figure 5.11: Attenuation of gamma rays in tungsten.

5. Warning signs must be posted at specific locations.
6. No one may be exposed to more than the permissible doses. The low allowable exposure levels requires more shielding. At high energies in the megavolt region with high workloads, the additional shielding may be extremely expensive. For example, in the case of cobalt-60, the required concrete thickness will have to be about 0.3 m (1 ft) greater than for iridium-192.

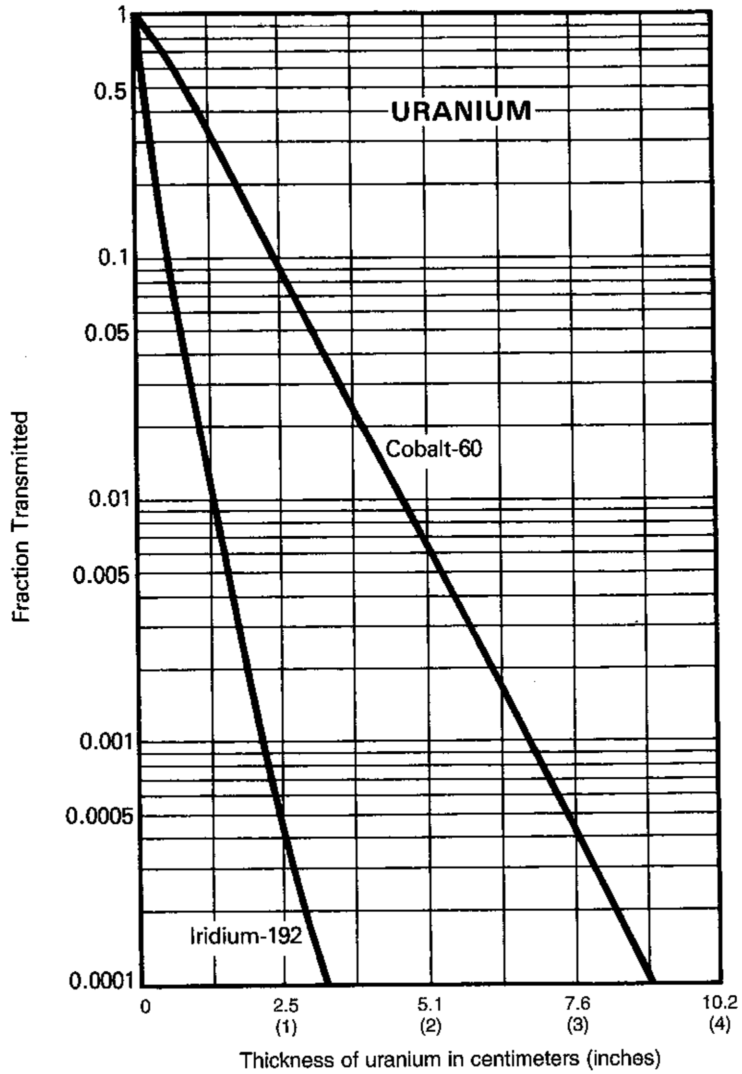


Figure 5.12: Attenuation of gamma rays in uranium.

Enclosed Installation

This class usually offers the greatest advantages for fixed installations with low use and occupancy. With proper supervision an enclosed installation offers a degree of protection similar to the protective installation. The requirements for an enclosed installation include items 1, 2, 3, 5 and 6, above, plus a different item 4.

4. The exposure at any accessible and occupied area 0.3 m (1 ft) from the outside surface of the enclosure does not exceed 100 µSv (10 mR) in any 1 hour.

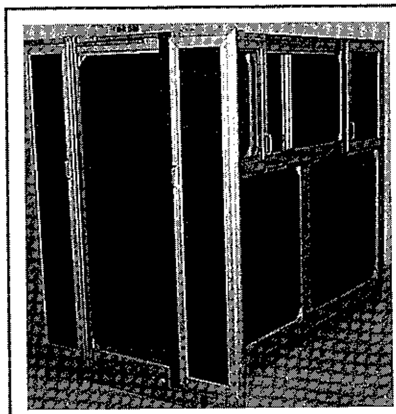


Figure 5.13: A modular enclosure which offers radiation shielding.

The exposure at any accessible and normally unoccupied area 0.3 m (1 ft) from the outside surface of the enclosure does not exceed 100 µSv (100 mR) in any 1 hour. Enclosed installations require procedures to avoid exceeding permissible doses.

Unattended Installation

This class consists of automatic equipment designed and manufactured by a supplier for a specific purpose that does not require personnel in attendance for operation. The requirements for this class include the following.

1. The source is installed in a single purpose device.
2. The source is enclosed in a shield, where the closed and open positions are identified and a visual warning signal indicates when the source is on.
3. The exposure at any accessible location 0.3 m (1 ft) from the outside surface of the device cannot exceed 20 µSv (2 mR) in any 1 hour.
4. The occupancy in the vicinity of the device is limited so that the dose to an individual cannot exceed 1 mSv (0.1 rem) in a year.
5. Warning signs are posted.
6. In areas where exposure can exceed the measurements in items 3 and 4 above, service doors must be locked or secured.

Open Installation

This class can only be used when operational requirements prevent other classes, such as in mobile and portable equipment where fixed shielding cannot be used. Mobile or portable equipment used routinely in one location should be made to meet the requirements of one of the fixed installation classes. The requirements include the following.

1. The perimeter of any area in which the exposure can exceed 1 mSv (100 mR) in any 1 hour must be posted as a *high radiation area.*
2. No unauthorized or unmonitored person may be permitted in the high radiation area during irradiation.
3. The perimeter of any area in which the radiation level exceeds 50 μSv (5 mR) in any 1 hour must be posted as a *radiation area.*
4. The equipment essential to the use of the source must be inaccessible to unauthorized use, tampering or removal.
5. No person can be exposed to more than the permissible doses.
6. Restricted areas must be clearly defined and marked. Surveillance to enforce the restrictions is needed.

Discussion

Discuss to make practical use of time, distance and shielding on the job to reduce your radiation dose.

Questions

1. Your radiation survey meter reads 100 μSv/h (10 mR/h). What dose will be delivered in 1 min? 15 min? 1 hour? 40 hours?

2. You note that your pocket dosimeter has picked up 30 μSv (3 mR) after a 5 min exposure. What was the radiation dose rate?

3. List four situations in which you could use time to reduce your radiation exposure on the job.

4. The dose rate at 30.48 m (100 ft) from a radiography source is 30 μSv/h (3 mR/h). What is the dose rate at 6.1 m (20 ft)? 13.72 m (45 ft)? 304.8 m (1000 ft)? 0.3 m (1 ft)?

5. You are working with a 1.9 TBq (50 Ci) iridium-192 source. What is the dose rate at 30.48 m (100 ft)?

6. You are working with a 2.8 TBq (75 Ci) cobalt-60 source. What is the dose rate at 15.24 m (50 ft)?

7. List four situations in which you could use *distance* to reduce your radiation exposure on the job.

8. Nuclear Regulatory Commission regulations state that the radiation dose cannot exceed 20 μSv (2 mR) in any 1 hour in an unrestricted area. Assume you are performing radiography 30.48 m (100 ft) from an unrestricted area. You are using a 2.2 TBq (60 Ci) iridium-192 source and each shot requires a 90 second exposure of the source. How many exposures can be made in 2 hours at this location? (The exposure rate from an iridium–192 source at 0.3 m (1 ft) from the source is 50 mSv/h (5 R/h per curie.)

9. What is generally the most practical way for a field radiographer to use shielding to reduce dose?

10. With an iridium-192 source, how much dose reduction can be achieved with a 2.54 cm (1 in.) thick collimator of lead? Of tungsten? Of uranium?

11. The dose rate from a cobalt-60 source with no collimator is 200 μSv/h (20 mR/h) at a distance of 30.48 m (100 ft). What is the dose rate with a tungsten collimator that is 2.54 cm (1 in.) thick?

12. Cobalt-60 is used in a fixed facility with concrete walls. The dose rate outside the wall in one spot is 100 μSv/h (10 mR/h). How much extra concrete thickness would have to be added to reduce the dose rate to 20 μSv/h (2 mR/h)?

Chapter 6

How Is Radiation Detected and Measured?

Radiographers use two types of devices to detect and measure radiation: *dose rate devices* and *absorbed dose devices*. With a portable handheld radiation survey meter, by reading the meter dial, the radiographer will get a measurement of the radiation *dose rate* at that moment and place. Radiographers will also have a combination of a direct reading dosimeter and operating alarm rate meter and either a film badge or a thermoluminescent dosimeter (TLD). *Dosimeters* record the total radiation *absorbed dose*. Radiation survey meters read *milliroentgen per hour (mR/h)*, a dose rate, and dosimeters read *milliroentgen (mR)*, a dose. The SI units are *millisieverts per hour (mSv/h)* for dose rate and *millisieverts (mSv)* for dose.

Survey Meters Measure Dose Rate

Survey meters used by radiographers generally use a cylindrical tube filled with gas to detect radiation. The tube is usually inside the survey meter case, but can also be connected to the case by an electrical cable.

Gas filled tubes are used in two types of survey meters: the *ionization chamber* (or *ion chamber*) *survey meter* and the *geiger-mueller survey meter*.

Both ionization chamber instruments and geiger-mueller survey meters are accurate enough for measuring the gamma rays used in gamma radiography. Geiger-mueller survey meters are most often used because they are rugged and highly sensitive to small amounts of radiation.

Certain geiger-mueller survey meters must be used with care for radiography. When the radiation intensity is high, the pulses of current get so close together the survey meter may not respond properly. High intensity radiation fields may cause the geiger–mueller ionization chamber to saturate resulting in the survey meter reading dropping to zero.

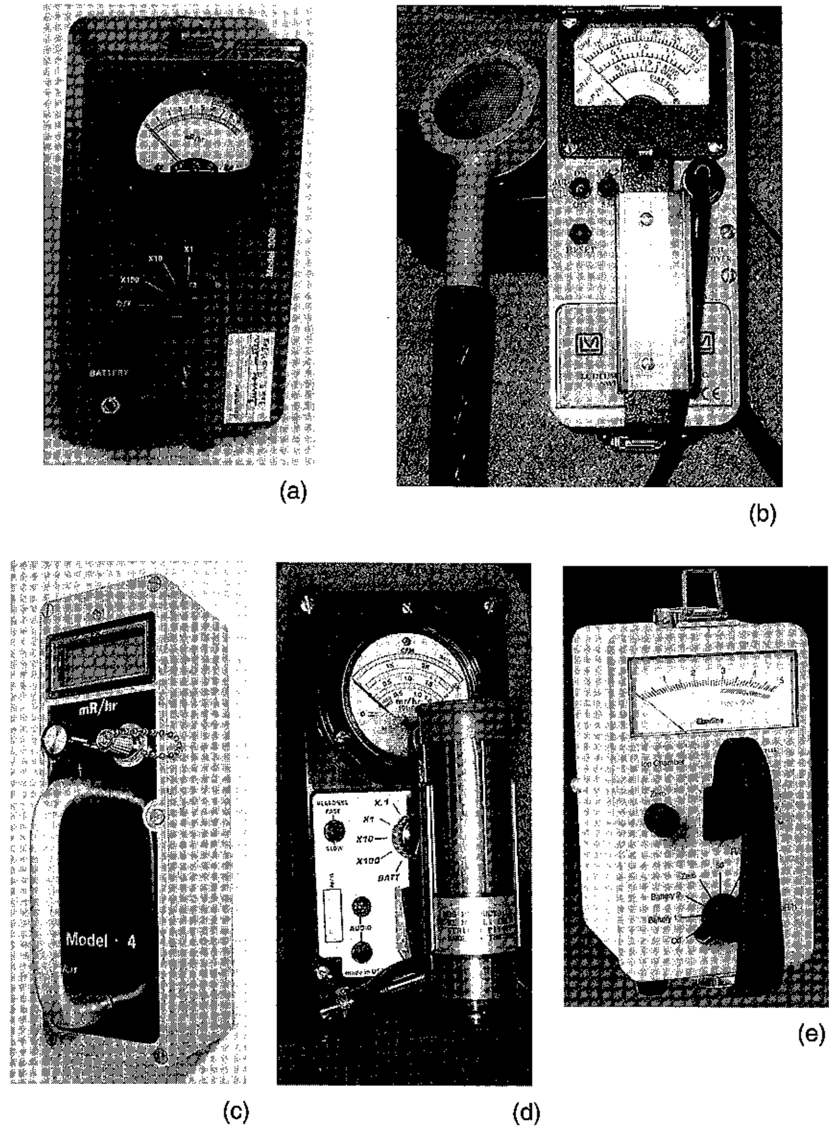
The survey meter must be able to read from 0.02 mSv/h to 10 mSv/h (2 mR/h to 1000 mR/h).

Reading a Survey Meter

Several survey meters are pictured in Figure 6.1. Figure 6.1(a) shows a typical geiger-mueller survey meter. The scale on the dial reads in mR/h. To determine the correct dose rate, look at the position of the range switch. If the range switch is set at ×10, the dial reading is multiplied by 10. If the range switch were set at ×100, the dose rate would be multiplied by 100.

Note the battery-check button on the lower left. (Many survey meters use the selector switch to a *battery* position.) Pushing this button tells whether the batteries are good or not. If the button is pushed, the needle should fall within the BATT CHECK bar on

Figure 6.1: Gamma and X-radiation sensing devices: (a) geiger-mueller survey meter with three ranges: 0-10 mR/h, 0-100 mR/h and 0-1000 mR/h, (b) survey meter with an external detector, (c) survey meter with automatic audible alarm, (d) survey meter with an external detector, (e) ion chamber survey meter.



the meter dial. If the needle falls to the left of the BATT CHECK bar, the batteries should be replaced before the meter is used. Otherwise, the survey meter will not operate properly.

When performing gamma radiography, radiographers will learn the rate at which the survey meter needle moves as the camera is approached. The speed of needle movement is a good way to judge how fast the dose rate is changing. You will also learn roughly where the needle should settle and how quickly it should settle there. The approximate dose rate is more important than a precise value because the position of the survey meter relative to the camera will be a little different every time a survey is made. On the other hand, for types of measurements where an operator must record a precise numerical value, digital displays can be more accurate than moving needles.

Figure 6.1(e) shows an ion chamber survey meter. The meter has a logarithmic scale. A logarithmic scale gets more compressed as the dose rate gets higher. Scales such as these were discussed in previous chapters. An ion chamber survey meter is operated in essentially the same way as a geiger-mueller survey meter. Ion chambers provide increased accuracy and increased dose range at an increased cost and perhaps a small loss of ruggedness.

Starting Work with an Operable Survey Meter

Never start work without an operable survey meter that has a current calibration. This is one of the most important rules in performing radiography. Without an operable survey meter, a radiographer cannot be sure that the source is shielded within the camera when it is supposed to be.

The most common cause of survey meter failure is weak batteries. The batteries should be checked each day when a survey meter is taken for use. Most survey meters have a *battery-test* position. When the switch is moved to the battery-test position, the meter needle should fall within a marked range on the meter. After radiography has been completed and the survey meter will not be needed for some time, switch it off. This will prolong the life of the batteries.

Fresh batteries typically last for about 100 to 200 hours of operation, but even newly purchased batteries may not always be fresh and may give considerably shorter life. If there is a short circuit in the instrument (possibly caused by dirt, moisture or damage) or if the instrument is accidentally left on for several days, the batteries can wear out sooner than expected. It is important to always carry extra batteries to guarantee an operable survey meter.

Next, check the meter's response to radiation. Some survey meters have a small radiation source built into the instrument. Moving a switch to the *source-check* position should give a response within an appropriate range.

If the survey meter does not have this feature, place the survey meter against the radiography camera. From previous measurements, what dose rate to expect should be known. If the survey meter does not respond as expected, return it for maintenance and obtain a properly working instrument. If the meter gives the expected dose rate, move the survey meter away from the camera. The meter needle should fall. With a little experience radiographers will be able to tell if the needle is falling at the expected rate.

A survey meter that is operating properly when work is started, can break during the day. If the meter starts to read abnormally high in the field and no spare is available, check the high reading using the following techniques.

Use shielding. Put the meter behind some shielding material such as 2.54 cm (1 in.) of steel or 15.24 cm (6 in.) of concrete. Does the reading drop? Is the drop the expected amount? (Refer to the attenuation graphs in Chapter 5.)

Use distance. Back off to twice the distance. Does the reading drop to about one quarter of its former value? If so, the meter is responding properly. (Use the inverse square law discussed in Chapter 5.)

If it is concluded that the meter is working properly, the high reading may mean the source is exposed. Go back to the crank and try to retract the source again. If this does not produce results, follow the company's emergency procedures.

If it is determined the meter is not working properly, return the source to the shielded position and stop work until the survey meter is replaced. Do not approach the camera without a working survey meter.

Though survey meters can be quite rugged, they can still be damaged by rough handling. Wires inside the case can come loose, the geiger-mueller tube can break, battery connections can come off and the meter mechanism itself can break. Handle the survey meter carefully. Never throw it into a truck or use it as a hammer.

Water inside the case can cause a survey meter to fail by causing a short circuit or battery failure. Salt or other chemicals can corrode the electronic circuits and cause the survey meter to fail. Cases are generally made to be watertight, but a bent or cracked case may leak. Damaged cases should be repaired or replaced.

Making a Radiation Survey

The most important radiation survey is the survey made *after* an exposure to verify the source has returned to its fully shielded position in the camera. The following is a general description of this survey. Survey procedures may vary somewhat based on each company's operating procedures and specific work conditions.

After returning the source to the camera, look at the survey meter. Note the needle position. Is it about where it should be? Approach the guide tube and camera. Is the needle rising at about the expected rate? Survey completely around the camera (360 degrees) and move the survey meter along the guide tube. Is the needle position about right?

Survey the camera. The survey of the front of the camera is very important because a source that is almost, but not completely, retracted can have a thin beam of radiation coming out the front.

Place the survey meter against the camera surface at a place where the reading level is known. Is the needle position about right? Secure the source in its shielded position by pushing the plunger or turning the locking ring.

If the readings are unexpected, something is wrong. A source could be exposed or the survey meter could be malfunctioning. At this point the radiographer will have to analyze the situation to determine what is wrong. It is normal to want to believe that the survey meter is wrong. Resist that temptation. *Assume the source is exposed until the problem is understood.*

Another important survey to make is to verify that the restricted area boundaries are properly set. A survey is usually conducted during the first exposure. Signs and ropes have been setup based either on calculations or on previous experience with similar situations.

Carefully note the setup. Note where beams of radiation could occur. If using a collimator, in which directions will there be unshielded beams? Is there any intervening shielding (such as pipes and concrete walls) to affect the readings?

Based on observations of the situation, make measurements of the dose rates at enough points on the boundary of the restricted area to be sure the boundary is set up properly. Repeat these measurements during later exposures or any time the setup is changed in a way that might change the dose rate at the restricted area boundary.

Calibration

Survey meters must be calibrated at least every 6 months as required by the Nuclear Regulatory Commission. Every survey meter should have a label indicating the last calibration date and the date of the next calibration. Later calibration requires placing the survey meter at a point from a source where the dose rate is known. If necessary, the survey meter can be adjusted to produce the desired reading on the instrument (Figure 6.2).

Most instruments used have several ranges and each range is calibrated independently of the others. The usual procedure is to calibrate the instrument at two points on each range. These points should be approximately one third and two thirds of full scale. Calibration must be such that accuracy within plus or minus 20% of the calibration source can be demonstrated at each point checked.

This calibration should be performed by someone who has been trained to do it.

Dosimeters Measure Dose

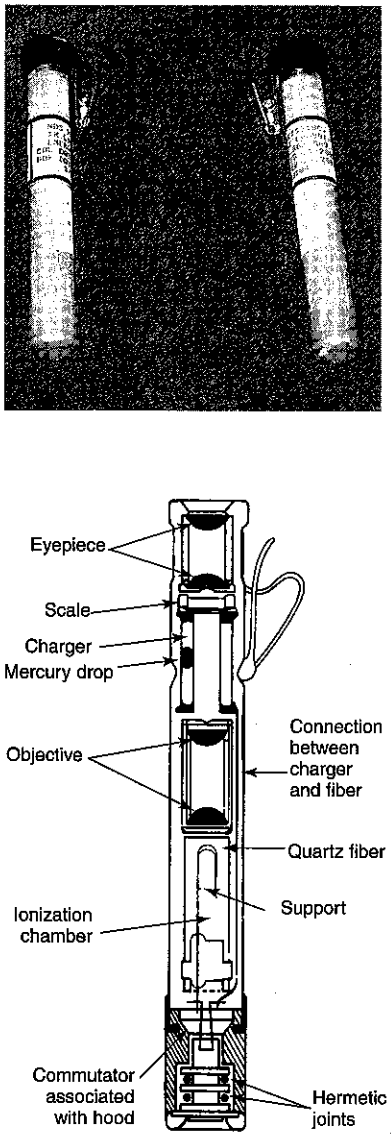
In addition to the radiation survey meter, which can measure dose rate continuously, radiographers are required to carry two devices to measure the radiation dose received. The two devices are a direct reading dosimeter and a personnel monitoring device such as a film badge or a thermoluminescent dosimeter (TLD). The radiographer is also required to carry an operating alarming rate meter, which will emit an audible alarm when a field of 5 mSv/h (500 mR/h) is entered. This, like the survey meter, is a *dose rate meter*.

The direct reading dosimeter provides an immediate measurement of dose received at any time. The film badge or thermoluminescent dosimeter must be processed by the supplier, but provides a much more accurate measurement of the dose received.

Direct reading dosimeters, film badges and thermoluminescent dosimeters determine what dose has already been received. They do not replace the survey meter. These dosimeters do not give any warning that the dose rate is high.

Figure 6.2: Instrument calibration station.

Figure 6.3: Pocket (direct reading) ionization chamber and cross section.



Survey meters tell how fast the dose is being delivered so that radiographers can protect themselves if the dose rate is high.

Pocket Dosimeters

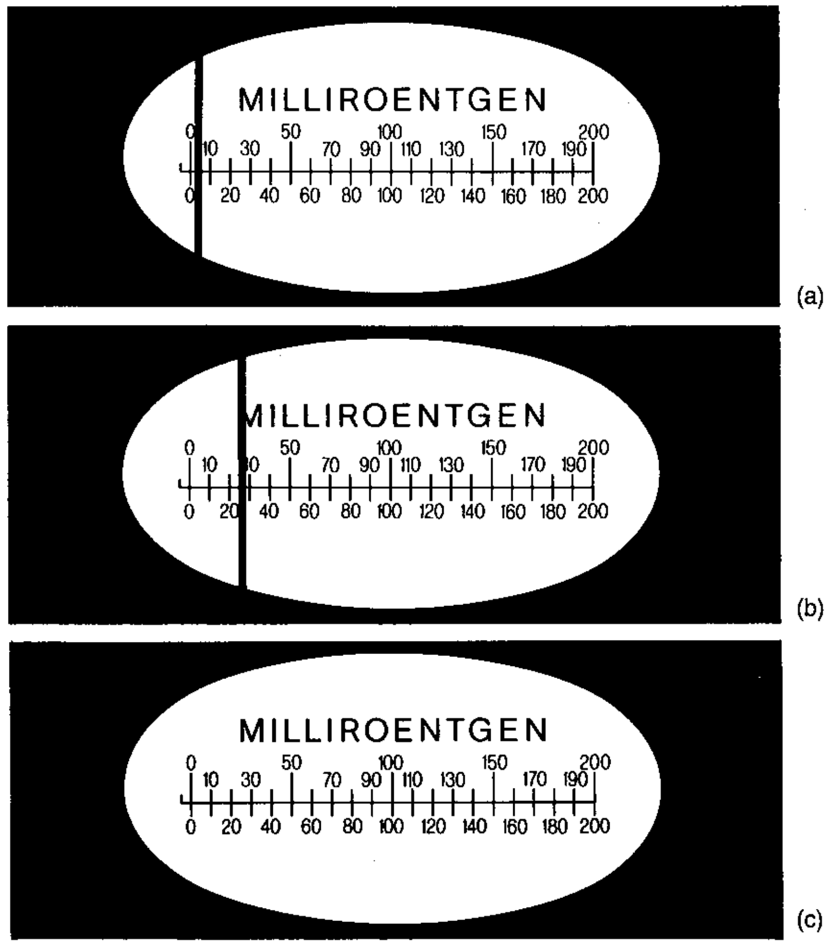
A self reading pocket dosimeter is basically an air filled ion chamber. Self reading pocket dosimeters must be checked at periods not to exceed 12 months for correct response to radiation. A cross section of a self reading pocket dosimeter is shown in Figure 6.3. A fine quartz fiber is attached to a charging electrode. A charger is used to place an electric charge (electrons) on the electrode. The quartz fiber is free to move except where it is attached to the electrode. When the dosimeter is charged, the fiber has the same charge as the wire. The fiber is repelled from the wire because electrons repel each other.

If the dosimeter is exposed to ionizing radiation, the ions created will neutralize the charge on the fiber and wire. As the charge is neutralized, the force repelling the fiber and wire will decrease and the fiber will move toward the wire.

The image of the quartz fiber can be seen by looking through the dosimeter. The image is projected on a scale that is divided into segments that can be read by looking into the eyepiece. The scales usually have divisions at each 10 mR (Figure 6.4). When the dosimeter is fully charged, the image of the fiber is made to rest at the 0 position on the scale. The dosimeter used by radiographers must have a full scale reading of at least 200 mR.

While pocket dosimeters are quite rugged, they can be damaged by being dropped or struck by a hard object. Even if there is no damage, such shock

Figure 6.4: Image viewed in a self reading pocket dosimeter.



(a) Dosimeter fully charged. The quarts fiber rests near 0 on the scale.
(b) Dosimeter exposed to radiation. The reading is 26 mR.
(c) Fully discharged dosimeter. The fiber is off the scale.

may cause the dosimeter needle to go off scale.

All pocket dosimeters will lose electric charge by leakage. If a dosimeter is working properly, this natural leakage will be so small that the dose recorded over a working day will not be affected. If a dosimeter becomes dirty or damaged mechanically, it might lose charge rapidly. Such loss of charge will produce false high readings of dose.

Following is a list of procedures that should be followed when using self reading pocket dosimeters.

1. The calibrated dosimeter should be charged at the start of work. Record the initial reading.
2. Clip the dosimeter firmly to clothing. Always wear it while doing radiography.
3. Read the dosimeter periodically during radiography. A high reading can mean that something is going wrong. Record the pocket dosimeter reading at the end of work.
4. If the dosimeter is dropped or damage is suspected in some other way, check the reading to see if it appears normal.
5. If the dosimeter reads off scale, the company radiation safety officer should be notified and the film badge or thermoluminescent dosimeter processed. Stop work until the radiation safety officer determines it is safe to return to work.

Film Badges

A film badge is a dosimeter containing a piece of film similar to the film used in making radiographs. Ionizing radiation darkens the film – the darker the film, the higher the dose. The dose on the film is read with a *densitometer*.

To produce the proper response and allow the processor to interpret the response correctly, the film must be held in a specially designed badge (Figure 6.5). The film badge contains metal absorbers or filters to tell how penetrating the radiation was and, therefore, whether the exposure was caused by high energy or low energy radiation. From this information, the company processing the film badge can calculate the dose.

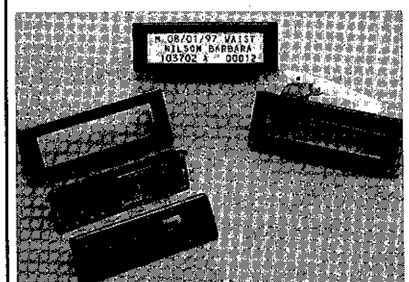
Film badge readings form the basis of a person's permanent dose record (Figure 6.6). The badge must be worn at all times while working. If the pocket dosimeter goes off scale, only the film badge or thermoluminescent dosimeter will provide technicians with the dose received.

Film badges are rugged, but they can be damaged by light, heat and moisture. If the paper covering the film is torn or punctured, the film will be ruined by exposure to light. Film can also be damaged if heated over about 130 °F. Leaving a film badge in a closed automobile on a hot summer day will produce fogging of the film so that an estimate of radiation exposure is difficult. Submerging a film badge in water or laundering can also damage the film.

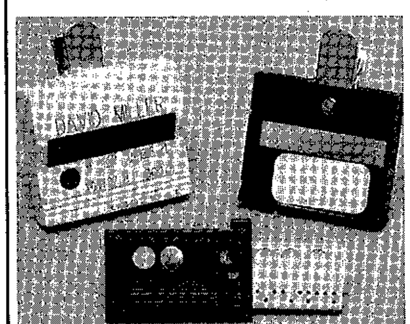
Thermoluminescent Dosimeters

Thermoluminescent dosimeters are similar to film badges in appearance and can be used by radiographers in place of film badges. Thermoluminescent dosimeters contain crystalline materials that store energy deposited by radiation. The energy deposited can be measured by heating the

Figure 6.5: Clip-on personal radiation dosimeters: (a) film badges; (b) thermoluminescent dosimeters.



(a)



(b)

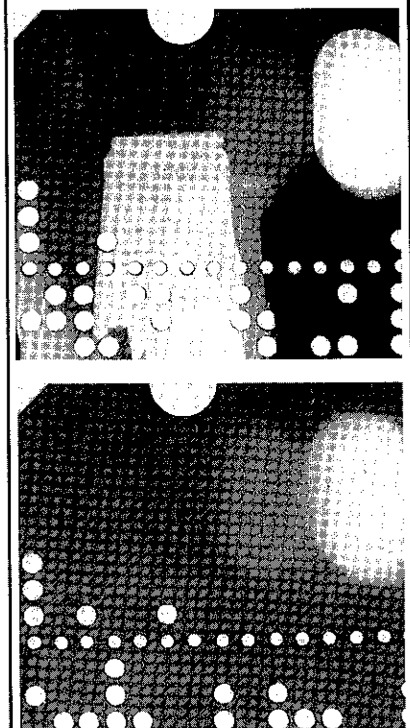
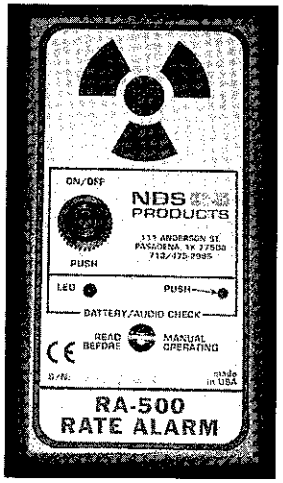


Figure 6.6: Looking at exposed film from a badge can tell a lot about how an exposure happened. The film on the top shows a clip, telling that the exposure came from the back. The film on the bottom shows the direction the radiation came from. In the event of an accident, the film can help determine what happened.

Figure 6.7: An audible alarm dosimeter.



crystalline material and measuring the energy released as light. A special reader measures the amount of light emitted.

These recommendations should be followed when using a film badge or thermoluminescent dosimeter badge.

1. Clip the badge firmly to your clothing (between the waist and neck) and always wear it while doing radiography.
2. Do not expose the badge to high temperature or water.
3. Stop work if the badge is lost or damaged. Submit a damaged badge to the radiation safety officer and get a new one. Report a lost badge to the radiation safety officer immediately.
4. Processing of badges is done on a regular schedule. Know the schedule and have the badge available for processing.

Alarm Rate Meter

Audible alarm rate meters (Figure 6.7) are instruments that are worn and will sound an alarm at a prescribed dose rate 5 mSv/h (500 mR/h). They can potentially save a radiographer from a radiation exposure if the survey meter fails.

Noise levels from alarm rate meters are sometimes too loud and annoying and other times not loud enough to be heard over background noises in the work area. Vibrating and flashing devices are available for work in high noise areas.

Audible alarm dosimeters are calibrated annually and are tested before beginning work. They can be a valuable aid if handled carefully and used under suitable conditions. Do not substitute them for a survey meter.

Alarm Systems at Permanent Installations

If the radiography company has a permanent installation or radiography cell for performing radiography, regulations such as 10 CFR Section 34.29, *Permanent Radiographic Installations* require that a special alarm system be installed (unless the source retracts automatically upon attempted entry). The alarm system, often called a *gamma alarm*, must have a warning light that is activated by radiation. Therefore, a radiation detector must be installed so that an exposed source can be detected. The warning light must operate whenever the source is exposed.

The gamma alarm is also required to sound if the cell is entered while the source is exposed. An automatic switch on a door or an electric eye in a maze entrance can be used to activate the audible alarm.

Testing Sources for Leaks

Radiography sources may not be used unless they have been tested for leaks within the previous 6 months, as required by Nuclear Regulatory Commission regulations in 10 CFR Section 34.25(b), *Radiation Survey Instruments*. A leaking source could spread radioactive materials outside the camera where the radiation would not be shielded.

Source manufacturers test sources for leaks before they are sent to the licensee. A manufacturer's certification that a source has been leak tested is shown in the upper right hand corner of the decay curve for a source. This certification gives the date the manufacturer tested the source for leaks.

The first step in making a leak test is to use a piece of cloth to pick up any loose radioactive material that may be present. The radiographer will then survey the cloth with a survey meter to make sure it is not highly contaminated. If there is a reading on the survey meter, the radiographer should follow company procedures and contact the radiation safety officer.

If the survey meter does not detect *any* radiation, the radiographer will send or give the cloth to someone who has been specially trained to make a leak test measurement. The leak test measurement can be performed only by people specifically trained to do so. A special radiation detection instrument and special procedures are also needed.

If radioactive contamination is found on the cloth in excess of 185 Bq (0.005 μCi) the equipment must be withdrawn from use and decontaminated. A report of the leaking source must be filed with the Nuclear Regulatory Commission or Agreement State within 5 days of discovery.
[10 CFR Section 34.25(b)]

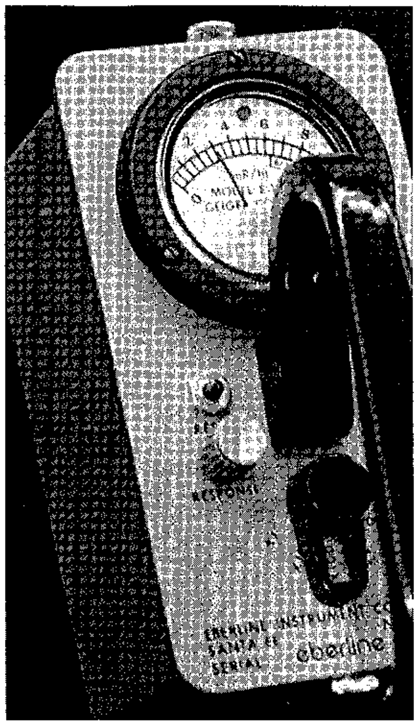
Questions

1. What are the measured exposure rates based on the following survey instrument readings?

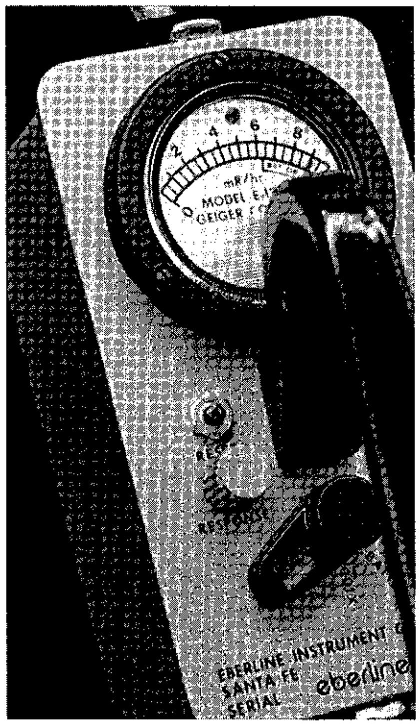
(a) ____________________ (c) ____________________

(b) ____________________ (d) ____________________

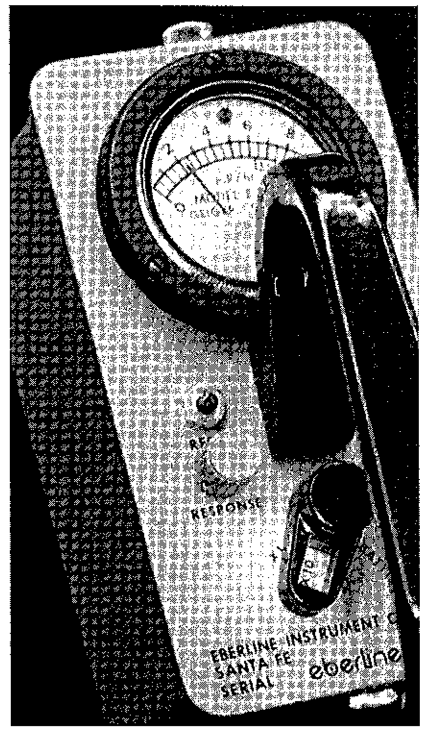
(a)



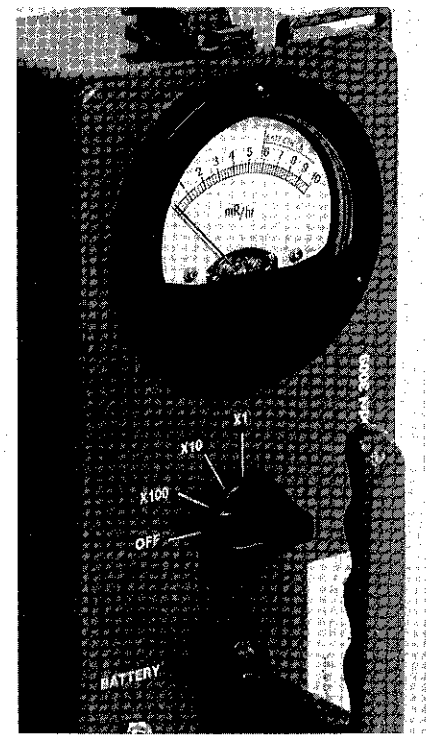
(b)



(c)



(d)



2. What types of dosimetry must be worn by a radiographer on the job?

____

____

____

____

____

3. Select the best answer:
While performing radiography, you note that your pocket dosimeter reads off scale. What should you do?
   a. Recharge your dosimeter and continue working.
   b. Complete your work and record the fact in your dosimeter log.
   c. Follow your employer's procedures and have your film badge or thermoluminescent dosimeter sent out for immediate processing.
   d. Perform a radiation survey to make sure that radiation levels are what you expect.
   e. Both c. and d.

4. Select the best answer:
What is the most important thing you can do to avoid an overexposure to radiation?
   a. Always wear the personnel dosimetry provided.
   b. Always make proper radiation surveys.
   c. Request that an alarming dosimeter be provided for use.
   d. Keep a daily log of pocket dosimeter readings.

5. Select the best answer:
Which of the following are the proper steps to take in making a survey after an exposure?
   a. Advance toward the camera, survey the guide tube, survey the front of the camera, survey sides and back of the camera.
   b. Advance toward the back side of the camera, survey the back and sides while behind the camera, survey the front and guide tube connection, survey the guide tube.
   c. Advance toward the tip of the guide tube, survey the guide tube and the front of the camera, reach over the camera and survey the back.
   d. Any order or sequence of steps is permissible as long as the radiation level remains low as the radiographer approaches the camera.

6. Select the best answer:
If you arrive at a job and find that your survey meter is not operating properly, what should you do?
   a. Complete the job quickly while keeping a close check on your pocket dosimeter.
   b. Use past experience to judge where the restricted area boundary should be and complete the job.
   c. Send an assistant to obtain a new instrument while you complete the first exposure.
   d. Go get a properly operating survey meter.

7. After each radiography exposure, you must make a radiation survey. What is the major purpose for doing this survey?

8. From the time a camera is removed from storage for use on a job through the time the job is completed, what radiation surveys should you make?

9. What is the reason for using a self reading pocket dosimeter on the job? How frequently must the dosimeter reading be recorded on paper?

Chapter 7

How Do Radiography Cameras Work?

A *gamma radiography camera* is basically a shielded container for a radioactive source that emits gamma radiation. The camera has a means for changing the source from being fully shielded to being nonshielded. This allows the gamma rays being emitted by the source to be used to expose film.

Types of Cameras

A *crank out camera* exposes the source by pushing it out of the camera on the end of a cable to make radiographs.

With a *beam type camera*, the source may be moved within the camera to be in front of a hole in the shielding, or shielding may be moved from in front of the source.

An iridium-192 exposure device is shown in Figure 7.1 with a diagram of the camera workings. The source is in the center in a uranium shield. The tube that passes through the shield is called the *S tube*. It is shaped like the letter *S* so that gamma rays from the source cannot pass straight out of the shield without passing through the shielding material. Gamma rays travel in straight lines and cannot curve around the bend in the S tube. However, technicians should be aware that the exit part of the S tube will produce high amounts of radiation (shine) when the end cap is removed.

The lock is shown on the right hand side in Figure 7.1(a). When the camera is locked, the source cannot be pushed out. The drive cable or control cable is connected on the right. The drive cable will push the source out the front of the camera. A source guide tube will be attached to the front. The source will be pushed into the guide tube and guided to the place where the radiographer wants it to be to make the radiograph. Figure 7.2 shows the drive cable with a crank and the source guide tube that the radiographer will attach to the camera.

The camera shown in Figure 7.1 is portable, weighs about 20.4 kg (45 lbs) and has a capacity of 5.55 TBq (150 Ci) of iridium-192. It contains 19.5 kg (43 lbs) of depleted uranium and is designed to be hand carried by one person. This portability and the ability to operate without electricity are great advantages in many industrial applications.

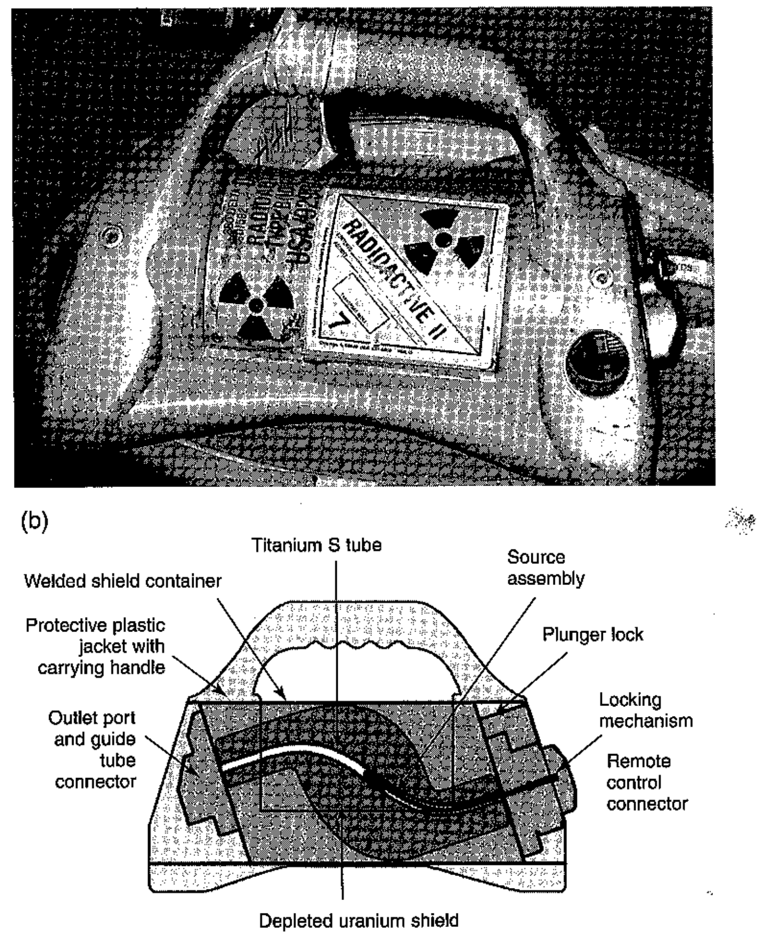
Using uranium as the shielding material greatly reduces the camera's size and weight and increases its portability. Some cameras use lead for shielding, but lead is less effective as a shield and increases the size and weight of the camera. As discussed in previous chapters, pound for pound, uranium is a much better shielding material than lead.

The maximum exposure rate limits for storage containers and source changers are 2 mSv (200 mR) per hour at any exterior surface and 0.1 mSv (10 mR) per hour at 1 m from any exterior surface with the sealed source in the shielded position. [10 CFR Section 34.21, *Limits or Levels of Radiation for Radiographic Exposure Devices and Storage Containers*]

Cameras that use cobalt-60 are not usually portable (Figure 7.3), but their principle of operation is very much the same. Cobalt cameras are too heavy to be carried by one person because of the additional shielding required.

Figure 7.1: Iridium-192 exposure device (a) photograph; (b) diagram.

(a)

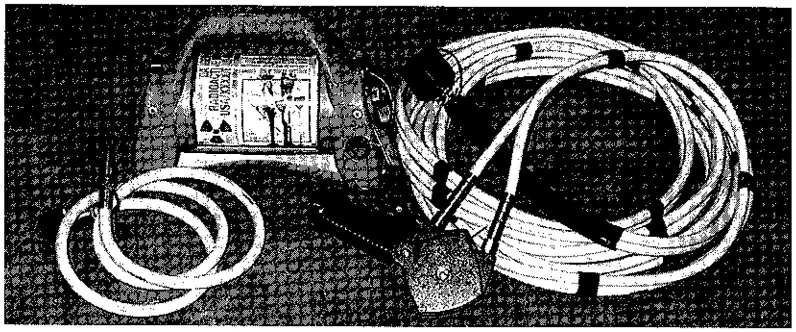


Daily Maintenance

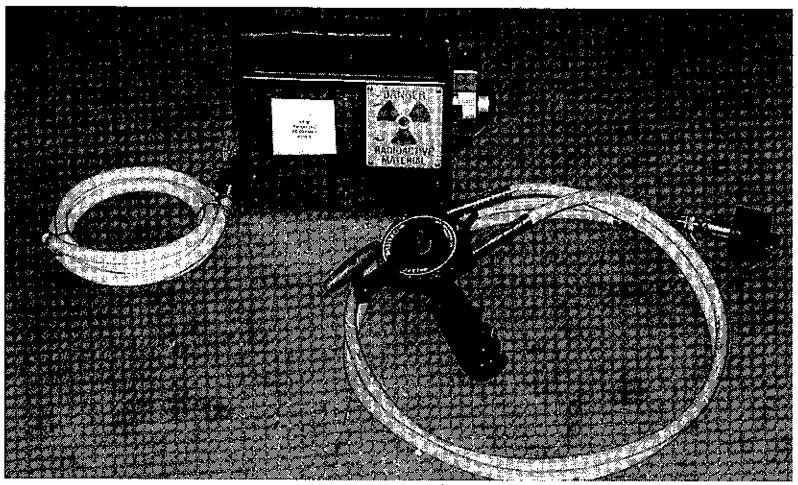
Before starting work with a camera, the camera should be checked to see that it is in good operating condition. Following are the general principles of maintenance. The detailed procedures provided by the employer should be followed.

The description below of a daily check was written for crank out cameras. But it can be adapted to beam type cameras.

Figure 7.2: Portable crank out cameras and drive cables.



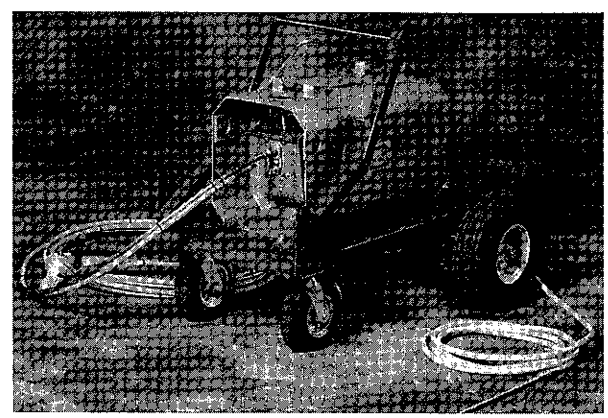
(a) 880 exposure projector and control system.



(b) 660B source projector and controls system with training crank and cables. Training cameras look and work like real cameras, but do not have the depleted uranium shielding. The cranks and guide tube are often shorter to make them easier to work with in a classroom setting.

1. Make a radiation survey of the camera. The radiation dose rate where the measurement is made should have its expected value. Survey the front of the camera. There should not be a beam of radiation, although the dose rate there may be a little higher than it is on the top or sides of the camera.
2. Check the camera for any visible damage.
3. Inspect the locking mechanism. Remove the cap, if any and inspect the portion of the pigtail that can be seen for frayed or broken strands or cracks. Figure 7.4 shows a radiograph of a pigtail cable whose strands have started to separate or *birdcage*. Do not unlock the camera yet.
4. Look at the pigtail connector for signs of wear. Look at the drive cable connection for signs of wear. The photos in Figure 7.5 show a radiographer using *go/no-go* gages to check for wear. This is a good thing to do. Also check connectors to verify that they are not bent.
5. Connect the drive cable, but do not unlock the camera yet. Remove the safety plug from the front of the camera. Check to see that the source outlet is round and smooth so that the source will not get stuck there when retracted.
6. Check the source guide tube for crimps, dents, fraying and dirt. Figure 7.6 shows a dent in a guide tube that could cause a source to jam in the tube. Attach the guide tube to the camera. Check to see that it attaches without difficulty.
7. Check the lock for ease of operation. Lubricate if necessary.
8. During the first exposure of the day, check for any hangups or binding as the source is cranked in and out.
9. If any problems are noticed, contact the supervisor and do

Figure 7.3: Cameras that use cobalt-60, like this one, are not usually portable. This camera has a capacity of 11.11 TBq (300 Ci) cobalt-60 and is constructed of stainless steel and titanium.



not use the camera until it has been repaired.

Figure 7.4: Birdcaging of a pigtail cable can cause eventual cable breaks or source hangups in the guide tube.

Quarterly Maintenance

Quarterly maintenance is performed by specially trained personnel. Often these people are not radiographers. Although this is called *quarterly* maintenance to indicate a periodic schedule, this maintenance should be performed whenever necessary. Depending on how the camera is used, maintenance may be needed more often. Sometimes a quarterly maintenance may find that no specific work is necessary. Generally, the supervisor will schedule the maintenance, but any problems noticed should be brought to his attention.

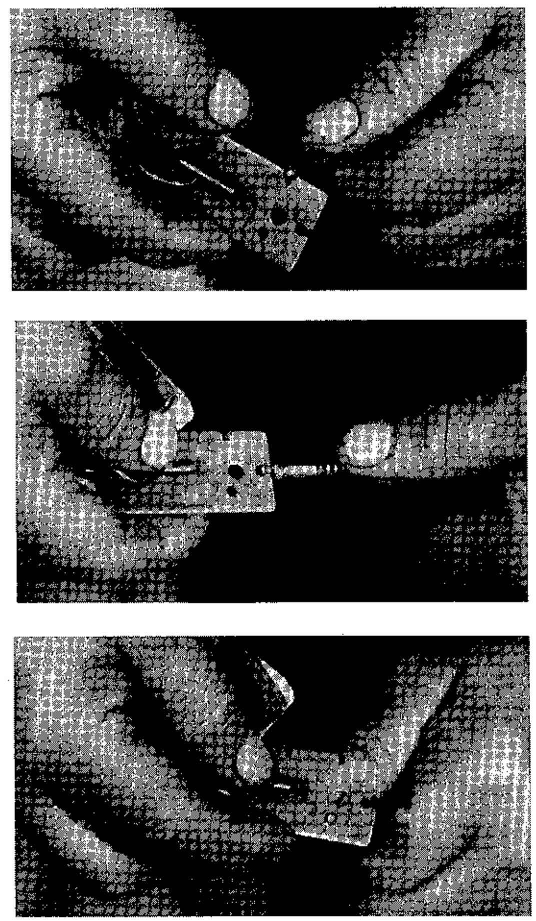
The most important thing is to clean dirt out of the guide tube, cranking mechanism and drive cables. Dirt clogged tubes, cables and cranks can make it impossible to fully retract the source. Dirt can also prevent the locking mechanism from operating correctly.

Whenever the guide tube and drive cables become dirty, they should be cleaned according to the manufacturer's instructions. One example of how to clean a camera would begin with disconnecting the drive cable from the crank and removing it from its protective tubing. Clean it in a recommended solvent. Pour a recommended solvent into the protective tubing and the guide tube. Blow the solvent out the other end using compressed air. Lubricate the drive cable as recommended. Lubricate the locking mechanism as recommended by the manufacturer. Note that each manufacturer has different requirements. Also, some companies may not allow technicians to take apart cranks for cleaning, or additional training may be required.

The camera should be periodically disassembled and cleaned. Components should be inspected for damage or wear and

Figure 7.6: This guide tube has been crushed. A source can get stuck here. The guide tube must be repaired or replaced.

Figure 7.5: Worn connectors can cause disconnects. This radiographer is using a *go/no-go* gage to check for wear.



(a) Inspecting the neck area of the connector on the control cable.

(b) Inspecting the ball on the connector on the cable for flat spots.

(c) Inspecting the ball on the connector on the control cable for side wear.

replaced as necessary. Disassembly, inspection and maintenance should be accomplished by the equipment manufacturer or by personnel that have been specifically trained if the license allows. Disassembly of a camera containing a source by untrained personnel could result in a serious radiation overexposure. Also, disassembly of a properly functioning camera may cause more problems than it solves, especially if the camera is not reassembled perfectly.

Discussion

This is a good time to ask the instructor questions about the operation and maintenance of the cameras you will be using.

Chapter 8

What Are the Basic Rules for Radiography?

"...Any person who willfully violates any provision of the Act or any regulation or order issued thereunder may be guilty of a crime and, upon conviction, may be punished by fine or imprisonment or both, as provided by law."
[NRC Regulations, Section 20.601]

Anyone who has worked with radiation has already been following the company's operating procedures. These procedures have been written to conform with federal and state regulations. Knowing these regulations will help with the understanding of a company's procedures. Understanding the regulations and following approved procedures may not necessarily lead to better radiographs, but it will lead to a safer work environment.

Who Regulates Radiographers?

Because of the hazards of radiation, the United States Congress passed a law giving the United States Nuclear Regulatory Commission the responsibility for regulating the use of most radioactive materials used in gamma radiography (such as iridium-192 and cobalt-60). X-ray radiography, accelerator radiography and radiography using radium-226 are regulated by the individual states and by the United States Occupational Safety and Health Administration (OSHA).

The Nuclear Regulatory Commission can relinquish to any state government its authority to regulate the use of radioactive materials in gamma radiography if the state (1) wants the authority, and (2) provides adequate resources to ensure that radioactive materials are used safely. As of June 2003, 32 states had accepted this responsibility and are called *Agreement States*. They have signed an agreement with the NRC that ends NRC authority within the state, except at federal institutions. The most current map of Agreement States can be found at the NRC Web site. (See Appendix B.) Gamma radiography in *non-Agreement States* is regulated by the NRC.

Each company must have a license to perform gamma radiography using radioactive materials. If a company is located in a state where the Nuclear Regulatory Commission regulates radiography (a non-Agreement State), the company must have a NRC license. If a company is located in an Agreement State, the company must be licensed by that state. If a company performs industrial radiography using X–rays only, the radiography is regulated by the state, whether it is an Agreement State or not. X–ray work performed on a federal site, such as an Air Force base, is under the regulation of NRC. X–ray equipment is not licensed, but is registered by states. Owners are required to renew registration annually.

Both the Nuclear Regulatory Commission and the Agreement States have regulations that must be followed. By federal law, Agreement State regulations must be compatible with NRC regulations. *Compatible* means that in certain important areas, the state regulations must be the same as NRC regulations. Though Agreement State regulations are much the same as the NRC's, they are not identical and may be more stringent.

Employers must provide a copy of relevant Nuclear Regulatory Commission regulations to their employees. Radiographers working in Agreement States must learn any differences between NRC regulations and the state's regulations. The addresses and telephone numbers of Agreement State regulatory agencies can be found at the NRC's State and Tribal Regulations Web site. Copies of the state regulations can be obtained from those agencies. Up-to-date copies of NRC regulations can be obtained at the Reading Room on the NRC Web site (Appendix B).

Reciprocity

What happens if a company is licensed in one state by either the Nuclear Regulatory Commission or by an Agreement State and wants to perform radiography in a different state where different regulations are in effect? The company may do so without applying for a new license because the license a company holds will be recognized and accepted in other states. This is called *reciprocity*. Details of reciprocity are found in NRC regulations, 10 CFR, Section 150.20, *Recognition of Agreement State Licenses*.

Reciprocity works the same for radiography licenses as for driver's licenses. Though driver's licenses are issued by the state where a person lives, each state recognizes the driver's licenses of every other state. The traffic laws of the state where a person is driving must be obeyed rather than the laws of the state that issued the license. The same is true for radiography.

For example, a company located in New York, an Agreement State, sends workers to a job in New Jersey, a non-Agreement State, where radiography is regulated by the Nuclear Regulatory Commission. The company must inform the NRC of the dates that employees will be working in that state by sending three copies of Form NRC-241 and three copies of its state license at least 3 days in advance.

After entering New Jersey, workers are subject to Nuclear Regulatory Commission's regulations. The regulations in effect are those of the state where the work is being performed rather than those rules of the state where the company is licensed.

Workers are also subject to inspection by the regulatory authorities of the state where they are working. In this case, workers would be inspected by Nuclear Regulatory Commission inspectors.

Companies wanting to work in an Agreement State where they are not licensed must inform that state in advance. Under reciprocity a company is usually limited to performing radiography a total of 180 days per calendar year in any Agreement State where it is not licensed. If the company keeps radiography sources in an Agreement State where it is not licensed for more than 180 days, it must obtain a license from the authority responsible in that state. Some Agreement States have limits different from 180 days.

Offshore Work Sites

Who regulates offshore work? Both the water and the land underneath the water off the shore or coast from any state are considered to be part of that state within an area of about 3 miles for most states and about 10 miles for the Agreement States of Florida and Texas. This area can be called a *state's territorial limit.*

Radiography performed within an Agreement State's 3 mile or 10 mile territorial limit is regulated by the state. Radiography performed outside the territorial limit (including the high seas) by any company licensed by the Nuclear Regulatory Commission or an Agreement State is regulated by the NRC.[1]

Each company should check Nuclear Regulatory Commission regulations [10 CFR Section 150.20] to determine whether it must notify NRC or the Agreement State before performing radiography beyond the 3 mile or 10 mile limit.

Nuclear Regulatory Commission Regulations

The Act of Congress that gave Nuclear Regulatory Commission the authority to regulate industrial radiography using radioactive materials also gave the agency the authority to issue regulations. These regulations are like laws, and it is illegal to disobey them. Violations of these regulations can result in monetary fines, loss of a company's license or even criminal penalties such as jail sentences.

The complete set of regulations issued by all federal agencies is called the *Code of Federal Regulations (CFR)* and can be found at the CFR Web site. (See Appendix B.) The code is composed of many *Titles* – different titles are issued by different federal agencies. Some titles are made up of several chapters. The Nuclear Regulatory Commission's regulations are Title 10 of the Code of Federal Regulations. This is often abbreviated 10 CFR.

Title 10 has one chapter but is composed of many separate *Parts.* In particular, Parts 19, 20 and 34 are especially important to radiographers. Copies of each of these parts must be provided to you for your training [Section 34.31(a)]. The notation in the brackets identifies specific sections in Title 10 of the Code of Federal Regulations. For example, [§ 34.31(a)] means paragraph (a) of Section 34.31 of Part 34.

Part 19 – Radiographers Bill of Rights

Part 19, *Notices, Instructions and Reports to Workers; Inspections,* could be called the Bill of Rights because it covers the rights of a worker. Following are the important provisions of Part 19.

1. Training [Section 19.12]

Employees have a right to adequate training to protect themselves against radiation. The employer must provide employees with adequate training to do the job safely and to avoid excessive exposure to radiation. Training is discussed more specifically for radiographers in Part 34 [§ 34.43]. Radiographers must also learn their company's own operating and emergency procedures.

2. Reports of Radiation Dose [Section 19.13]

Radiographers have a right to know the amount radiation to which they have been exposed. The employer is required to keep a record of each employee's radiation dose, such as on Form NRC 5. At an employee's request, the employer must disclose in writing each year how much radiation was received that year.

Companies must also provide former employees a record of their radiation dose within 30 days of the employee's request. The employer must report to the employee the dose received within 30 days if the employee has been overexposed. When employment is terminated, the employer must send the employee a report of the radiation dose received while employed by that company.

3. Talking to Nuclear Regulatory Commission Inspectors [Section 19.15(b)]

During an inspection, the radiographer has a right to talk to Nuclear Regulatory Commission inspectors. The radiographer can privately bring to the attention of NRC inspectors any safety concerns, either orally or in writing.

4. Requesting a Nuclear Regulatory Commission Inspection [Section 19.16 and Section 19.17]

Radiographers have a right to request that the Nuclear Regulatory Commission conduct an inspection if there are safety problems. These requests should be made in writing to the regional NRC office. The employer will be given a copy of the letter. However, the employee may request that the employer not be told who made the complaint or not be told the names of other workers mentioned in the letter.

Anyone not sure whether there really is a safety problem can call the Nuclear Regulatory Commission regional office to discuss the problem. Addresses and telephone numbers can be found at the NRC Web site. Employees have the right to expect that the NRC will pay careful attention to the problem.

Employees may not be fired or discriminated against in any way as a consequence of filing a complaint.

If the Nuclear Regulatory Commission does not agree that a safety problem exists, a response must be made in writing why the employer (the licensee) is not in violation of the regulations.

5. A Worker Representative May Accompany a Nuclear Regulatory Commission Inspector on an Inspection [Section 19.14]

If workers have selected someone to represent them, for example, by labor union selection processes, the licensee must inform the Nuclear Regulatory Commission inspector and must allow that person to accompany the NRC inspector during the inspection. The workers' representative must be routinely engaged in licensed activities under control of the licensee and must be trained in radiation protection (as described in Section 19.12).

Part 20 – Basic Radiation Safety

Part 20, *Standards for Protection Against Radiation*, sets down the basic terms and rules for radiation safety, including radiation dose limits. Following are only those requirements in Part 20 that are not covered in more detail in Part 34.

1. Radiation Dose Limits [Section 20.1201 and Section 20.102]

The Nuclear Regulatory Commission has annual (calendar year) radiation dose limits. Note: This manual is concerned only with radioactive sources located outside the body. In previous chapters it was mentioned that radioactive materials can also be taken into the body, for example, by inhalation. There are separate NRC limits for such intakes of radioactive materials. Those limits are not considered here because radiography sources are sealed inside steel capsules that rarely allow particles of radioactive material to be released into the air.

The following are the Nuclear Regulatory Commission limits for adults in areas where access is restricted for the purpose of radiation protection:

Dose Limits

1. An annual limit which is the more limiting of:
   a. The total effective dose equivalent being equal to 0.05 Sv (5 rem), or
   b. The sum of the deep dose equivalent and the committed dose equivalent to any individual organ or tissue other than the lens of the eye being equal to 0.5 Sv (50 rem).

2. The annual limits to the lens of the eye, to the skin and to the extremities which are:
   a. A lens dose equivalent of 0.15 Sv (15 rem), and
   b. A shallow dose equivalent of 0.50 Sv (50 rem) to the skin or to any extremity.

The whole body dose is a measure of the amount of radiation that has been received by a large portion of the body, particularly the parts important from a radiation protection point of view. These parts are the bone marrow where leukemia would originate or the gonads where genetic damage to offspring would originate. Usually the dose reading on the film badge or thermoluminescent dosimeter is considered to be the whole body dose. Whole body for external exposure is head, trunk (including male gonads), arms above the elbow or legs above the knee.

The annual occupational dose limits for minors are 10% of the annual dose limits specified for adults [Section 20.1201]. Note, however, that Department of Labor regulations prohibit individuals under the age of 18 from working in occupations involving exposure to radiation [29 CFR Section 570.120 and Section 570.57]. Minors are not allowed to work as radiographers.

There is a special limit on radiation dose to the skin from radiation that does not penetrate beyond the skin. This limit for the skin is rarely of interest to radiographers. Skin dose generally comes from beta particles, which usually do not have enough energy to reach deeply into the body and do not contribute to the whole body dose. The radioactive materials in radiography sources emit beta particles, but the beta particles do not penetrate the steel capsule containing the radioactive material.

2. Restricted Areas, Unrestricted Areas, Radiation Areas and High Radiation Areas

a. Restricted Areas [Section 20.1003]
A restricted area is an area to which the licensee restricts access for the purpose of radiation protection. Restricted areas are established to protect the public from radiation. Radiographers cannot let anyone into a restricted area unless the person has been told of the presence of radiation in the area and told what to do to avoid or control the exposure to radiation [Section 19.12]. At a field site, ropes and signs are frequently used to mark off the restricted area and keep people from entering. If people ignore the ropes, the radiographer should be prepared to tell them that a radiation source is in use and that they should keep away.

b. Unrestricted Areas [Section 20.1301]
An *unrestricted area* is an area where access is not restricted. The maximum dose allowed to anyone in any area where access is not restricted is 20 μSv (2 mrem) in any 1 hour and 1000 μSv (100 mrem) in a year. (In Chapter 5, problems on how to calculate doses such as 20 μSv (2 mrem) in any 1 hour were worked.) Often radiographers find it convenient to simply set up restricted area boundaries where the dose rate is less than 20 μSv/h (2 mR/h).

c. Radiation Areas [Section 20.1003(b)(2)]
A *radiation area* is an area in which anyone could receive a radiation dose to a major portion of the body in excess of 50 μSv (5 mrem) in any 1 hour or 1 mSv (100 mrem) at 30 cm (11.81 in.). Radiation areas must be posted with signs saying *Caution, Radiation Area* [Section 20.1902]. In radiography, the *radiation area* will be not very different in size from the *restricted area.* Therefore, it is often practical to post the radiation area signs at the restricted area boundary and not have a separate radiation area.

d. High Radiation Areas [Section 20.1902]
If the dose to anyone could exceed 1 mSv (100 mrem) in any 1 hour at a distance of 30 cm (1 ft), the area is a *high radiation area.* High radiation areas must be posted with a sign saying *Caution, High Radiation Area* or *Danger, High Radiation Area* and displaying the radiation symbol.

3. Receiving Radioactive Sources [Section 20.1906]

Licensees must promptly pick up packages containing radioactive sources from shippers within 3 hours if delivered during working hours, or 3 hours of the start of work if delivered after hours. This reduces the chance that someone unfamiliar with radiation will accidentally mishandle a potentially dangerous source. The licensee needs to survey and record the radiation levels at the surface and at 1 m (39.37 in.).

4. Reporting a Lost or Stolen Source [Section 20.402(a)]

The supervisor must be notified immediately if a radiography source is lost or stolen so that the company can immediately notify the regional Nuclear Regulatory Commission office (Appendix B). Radiography sources can be very dangerous to anyone who does not understand the danger or the precautions necessary for handling radioactive materials.

5. Reporting Radiation Overexposures [Section 20.2205 and Section 20.2209]

Overexposures must be reported to the Nuclear Regulatory Commission. An employer must immediately notify the NRC regional office (Appendix B) by telephone of anyone being overexposed to radiation. The NRC regional office must be contacted within 24 hours regarding a radiation overexposure exceeding 0.05 Sv (5 rem) to the whole body or a low dose equivalent exceeding 0.15 Sv (15 rem) or a shallow dose equivalent to the skin or extremities exceeding 0.5 Sv (50 rem) or the release of radioactive material inside or outside of a restricted area, so that, had an individual been present for 24 hours the individual could not exceed their annual limit. Lesser overexposures must be reported within 30 days.

Part 34 – Responsibilities [Section 20.2204]

Part 34, *Licenses for Radiography and Radiation Safety Requirements for Radiographic Operations,* contains some of the things that are required while performing radiography. The licensee has the responsibility in the eyes of the Nuclear Regulatory Commission to see that the regulations are obeyed. The company establishes operating and emergency procedures so that employees can work in a way that meets the regulations. However, because the employee is the person who must actually do the work, he becomes responsible to the employer to see that the regulations are obeyed.

It was mentioned that Part 19 forbids an employer from firing or discriminating against employees who complain to the Nuclear Regulatory Commission about safety problems, however, an employer may discipline or fire an employee who *fails* to obey the regulations.

The basic provisions of Part 34 that must be followed include the following.

1. Radiation Surveys [Section 34.49]

The most important thing that a radiographer must do to protect himself and anyone near him is to perform adequate radiation surveys with a survey meter. Most of the radiography overexposure accidents reported to the Nuclear Regulatory Commission happened when a radiographer did not make a survey or surveyed improperly. A survey meter must be used. Visual surveys alone are not acceptable.

The following surveys must be performed:

a. A survey of the camera and guide tube after each radiography exposure to verify that the source is in its shielded position. This is covered in previous chapters. A survey shall also be performed when the camera is placed in a storage area to ensure the sealed source is in its shielded position.
b. A survey of the *restricted area* boundary to make sure that no person outside the restricted area could receive a dose of more than 20 μSv (2 mrem) in any 1 hour. The survey meter will provide the *dose rate*, for example 0.1 mSv/h (10 mR/h). To obtain the *dose*, multiply the dose rate by the fraction of the hour that the source will be exposed. This is covered in previous chapters.

Those good at doing these calculations will be able to convert any survey meter reading into the dose. Otherwise assume that the source is exposed for the whole hour. As long as the meter reading is less than 20 μSv/h (2 mR/h), the dose at the *restricted area* boundary is acceptable.

2. Posting [Section 34.53]

Signs are posted to warn other people that radiation is present in the area and that they should be careful to avoid the area. Ropes are often used with the signs, although the regulations do not specifically require ropes. The radiographer must post *radiation area* signs, where the dose is sufficient to expose anyone to a dose of 0.05 mSv (5 mrem) in any 1 hour. *High radiation area* signs must be posted anywhere the dose is sufficient to expose anyone to a dose of 1 mSv (100 mrem) in any 1 hour at 30 cm (1 ft). No radiation survey is necessary at the *high radiation area* boundary.

High radiation area signs may be posted at the radiation area boundary and omit *radiation area* signs. But if this done, all the requirements for the *high radiation area* will apply to the entire area. The signs must be conspicuously posted so that anyone approaching these areas can see them [Section 20.1902].

3. Surveillance [Section 34.51]

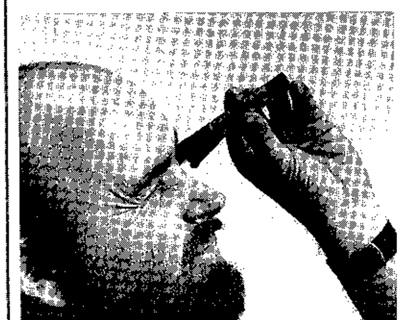
The radiographer is responsible to see that no one enters the *high radiation area* while a radiography source is exposed. Direct visual surveillance of the restricted area must be maintained and to prevent unauthorized access to the *radiation area* and *high radiation area*. Personal surveillance is not necessary at a permanent installation where all entryways are locked [Section 34.33]. Personal surveillance also is not necessary if the source will automatically retract when someone approaches or if there is an alarm system that will warn both the person and radiographer that the source is being approached [Section 20.1903(c)(2)].

4. Personnel Monitoring [Section 34.47]

Whenever working with a radiography source, a pocket dosimeter, an operating alarm ratemeter and a thermoluminescent dosimeter must be worn. The pocket dosimeter must be recharged and read every day and the results must be recorded (Figure 8.1). It is also a very good idea to read the dosimeter several times during the day to verify there has not been an exposure to radiation. If the pocket dosimeter reads off scale, the film badge or thermoluminescent dosimeter must be given to the supervisor

Figure 8.1: Pocket dosimeters being charged and being read.

(a) At the start of work, the radiographer charges the dosimeter. The dose the dosimeter indicates is recorded.



(b) This radiographer is checking the reading on this pocket dosimeter. This is a good check from time to time to make sure you have not received excessive radiation exposure.

for immediate processing. The employer must keep records of the radiation dose received [Section 34.47 4b,c].

5. Locking of Radiographic Exposure Devices [Section 34.23]

After each exposure, the source must be secured in the camera (not necessarily locked with a key) to make sure it is in a safely shielded position. Pushing down a plunger or rotating a locking ring are ways this can be done on different types of cameras. With changes to the manufacturing requirements, these methods are no longer necessary. Devices must automatically secure the source assembly when it is cranked back into the fully shielded position within the device. This securing system may only be released by means of a deliberate operation on the exposure device.

A radiography source cannot be left unsecured so that anyone who happens along could crank out the source and expose themselves to radiation. In addition, the camera must be locked with a key with the key removed whenever it will not be under direct surveillance or control.

6. Storage of Sources [Section 34.35

The radiography camera must be protected from being stolen, tampered with, or removed by any unauthorized person. Place the camera in a locked storage area or locked truck before leaving it unattended. Both the storage area and the truck must be posted with a sign saying *Caution, Radioactive Materials* and bearing the radiation symbol. A camera must not be left unattended in an unrestricted area — even if the source is locked in and the key removed from the camera.

7. Radiation Survey Instruments [Section 34.25]

All survey meters used must be calibrated every 6 months. If a survey meter has been repaired, it must be recalibrated before it can be used again. The survey meter must be able to read from 0.02 mSv/h to 10 mSv /h (2 mR/h to 1000 mR/h).

8. Leak Testing [Section 34.27]

Radiography sources must be leak tested every 6 months to make sure that radioactive materials are not leaking out of the source. Sources that have not been tested cannot be used.

9. Quarterly Inventory [Section 34.29]

Every 3 months the company must account for all the radiography sources it owns.

10. Utilization Logs [Section 34.71

The radiographer must make a record of where and when any radiography source assigned is used and in what camera or storage container it is being kept.

11. Inspection and Maintenance of Radiographic Exposure Devices [Section 34.31

The camera must be checked for obvious defects each day before use to make sure it is in good working order. Radiography cameras must also be inspected and maintained every 3 months. The person performing the quarterly inspection and maintenance should be specifically trained to do so.

12. Permanent Radiographic Installations [Section 34.33]

Permanent radiographic installations (except those with automatic source retraction devices) must have both visible and audible warning signals. The visible signal, such as a light, must be activated by radiation when the source is exposed. The audible signal must be activated if anyone enters the room while the source is exposed.

Note that the gamma alarm does not replace the security requirements for *high radiation areas* that were discussed earlier. The security requirements are to prevent unauthorized personnel from entering the high radiation area. The gamma alarm is to prevent the radiographer from mistakenly entering the room while the source is exposed.

13. Training [Section 34.43]

The radiographer must be instructed in the subjects covered in this training manual and must study case histories of radiography accidents. In addition, the radiographer must be instructed in the company's operating and emergency procedures. The radiographer must know how to operate the equipment to be used and pass a test on these subjects to show they are understood. This usually requires several months of on-the-job training.

14. Supervision of Radiographer's Assistants [Section 34.46]

A radiographer who is supervising a radiographer's assistant must be present, able to give assistance and be watching the assistant whenever the assistant uses a radiography source or makes a survey to determine that the source has returned to its safe shielded position after an exposure. Agreement State regulations must provide as much protection of public health and safety as Nuclear Regulatory Commission regulations. Violations of NRC regulations can result in monetary fines and loss of the company's license.

True or False

1. T F The use of X-rays to perform industrial radiography is regulated by the Nuclear Regulatory Commission.

2. T F Agreement State regulations must be very similar to the Nuclear Regulatory Commission regulations in all important safety matters.

3. T F Agreement State regulations must provide as much protection of public health and safety as Nuclear Regulatory Commission regulations.

4. T F If your company is licensed by an Agreement State, it can perform radiography only in that state or in another Agreement State.

5. T F Wherever you are working, you need to obey only the regulations in effect in the state where your company is licensed.

6. T F If your company has a Nuclear Regulatory Commission license and the job site is in an Agreement State, you must notify the state before starting work there. Radiography conducted beyond the 3 mile territorial limit is not subject to Nuclear Regulatory Commission or state regulations.

7. T F Radiography conducted beyond the 3 mile territorial limit is not subject to Nuclear Regulatory Commission or state regulations.

8. T F Violations of Nuclear Regulatory Commission regulations can result in monetary fines and loss of your company's license.

9. T F Your company must tell you the dose you receive each year, but only if you request it.

10. T F If you have been overexposed to radiation, your company must tell you that you have been overexposed.

11. T F If you quit your job, you can receive a record of the radiation dose you received, but only if you request it.

12. T F You can request that the Nuclear Regulatory Commission conduct an inspection of your company if you think there are safety problems.

13. T F You can talk privately to Nuclear Regulatory Commission inspectors during inspections.

14. T F If you write a letter to the Nuclear Regulatory Commission complaining of safety problems at your company, the NRC need not reply if it does not agree with your claims.

15. T F A worker representing the other workers at your company may accompany a Nuclear Regulatory Commission inspector during an inspection if he wants to.

16. T F The limit on radiation dose to the whole body during a 3 month period is 50 mSv (5 rem).

17. T F The Nuclear Regulatory Commission has a weekly dose limit of 12.5 mSv (1.25 rem).

18. T F Anyone who is not a radiographer or radiographer's assistant cannot enter a restricted area.

19. T F The maximum dose in any area that has unrestricted access is 0.05 mSv/h (5 mR) in any 1 hour.

20. T F Restricted areas must always be enclosed by ropes or other barriers.

21. T F Lost or stolen sources must be promptly reported to the Nuclear Regulatory Commission or an Agreement State.

22. T F You must always survey the camera with a survey meter after every exposure of the source.

23. T F You must survey the boundary of the *high radiation area* during every exposure of the source.

24. T F You must survey the boundary of the *radiation area* during every exposure of the source.

25. T F You must survey the boundary of the *restricted area* during every exposure of the source.

26. T F If the *restricted area* does not have locked doors, an alarm or an automatic source retraction device, you must maintain surveillance of the entire restricted area to make sure no one enters.

27. T F If you have a reliable pocket dosimeter, you do not also have to have a film or thermoluminescent dosimeter badge.

28. T F You must read your pocket dosimeter after each exposure.

29. T F You must recharge your pocket dosimeter weekly.

30. T F If your pocket dosimeter goes off scale, you should recharge it and return to work.

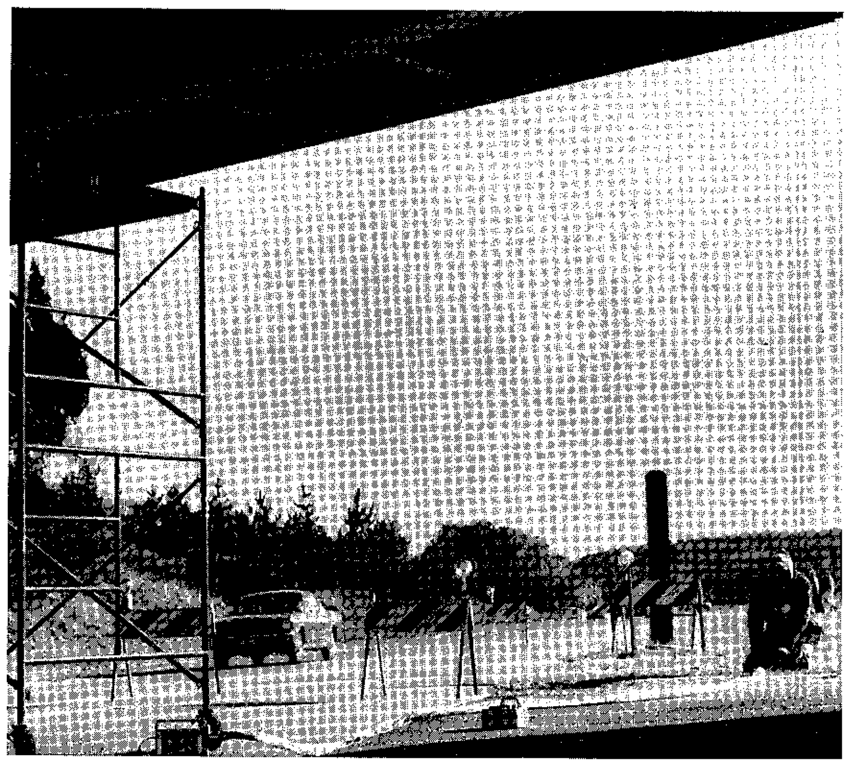
31. T F You can leave a camera untended in the back of a pickup truck if the source is locked and the key is removed.

32. T F You must check to be sure your camera is in good working order each day before starting work.

Questions

1. You are a radiographer working at a field site. You have established a restricted area and are getting ready for a shot. Another radiographer for some reason ignores the restricted area ropes and enters the area. When you approach him and tell him to keep away, he tells you that he has been a radiographer for more than 10 years and knows what he is doing. He refuses to leave the area. Should you proceed with completing the exposure or not?

Figure 8.2: Radiography on a highway overpass.



2. You have been a radiographer for 5 years when you are sent to a site to take some shots. When you get there and start setting up the shot you realize that the survey instrument that you brought with you is not working. You know that if you went back to your company to get another survey instrument you would waste a lot of time and you have done the same kind of exposure with the same source quite a few times in your 5 year career. What do you do?

3. You are setting up for a shot. You read your dosimeter and it reads off scale. You take all the necessary surveys and find out that the source is in its safe stored position and there is no abnormal radiation present. What do you do?

4. The radiographer in Figure 8.2 is inspecting a highway overpass. Discuss how you would set up and post *restricted, radiation* and *high radiation areas.* Where would you maintain surveillance?

Chapter 9

What Are the Rules for Transporting Sources?

The transportation of radioactive materials is highly regulated. The radiographer will be involved with regulated transportation of radioactive materials every time the camera is taken out into the field. This chapter is optional. It may be omitted by those who are not doing field radiography and are not responsible for receiving and sending out shipments of radioactive materials.

The United States Department of Transportation regulates the transportation of radioactive materials *between* states. The Nuclear Regulatory Commission and Agreement States also regulate the transportation of radioactive materials. NRC regulations [10 CFR Section 71.5] and state regulations require that some Department of Transportation regulations be met, so certain DOT regulations must be met whether the shipment crosses a state line or not.

The Department of Transportation regulations for transport of radiography sources are DOT *Hazardous Materials Regulations,* Parts 171 through 179 of Title 49 of the Code of Federal Regulations [49 CFR Parts 171–179]. An employer's procedures for transporting radiography sources are written to be consistent with federal and state regulations.

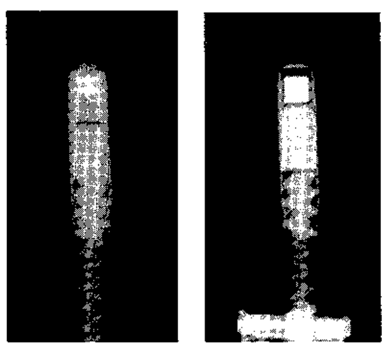
Packaging

Radiography sources must be properly packaged for transportation. The proper packaging depends on the amount of radioactivity involved and the form of the material: *special form* or *normal form.*

Special Form and Normal Form [49 CFR Section 173.389(a) and Section 173.398(a)]

Special form packaging means the radioactive material is contained in a leakproof, escapeproof capsule to prevent the spread of radioactive contamination. Radiography sources are special form. A radiography source is encapsulated in a high strength metal such as stainless steel as shown in Figure 9.1.

Figure 9.1: A radiograph of two sources. The radiographic material (white squares) is inside steel capsules. Radiography sources are *special form* because the radioactive material is sealed inside steel capsules.



Normal form radioactive materials are those in a form that does not give as much protection against escape of the radioactive materials and that does not qualify as special form. Examples of normal form material are glass or plastic vials of radiopharmaceuticals and radioactive waste material such as contaminated towels in plastic bags.

The remainder of this chapter deals only with special form materials because radiography sources are special form.

Amount of Radioactivity in Packages [49 CFR Section 173.389]

There are two special kinds of transporting packaging depending on the amount of radioactive material that they are allowed to contain: Type A and Type B. For special form materials, the radiation activity limits are as follows:

Packaging Type	Maximum Radiation Activity
Type A	999 GBq (27 Ci) iridium-192
	399.6 GBq (10.8 Ci) cobalt-60
Type B	Quantity greater than Type A

Most radiography sources will require Type B packaging. Old sources being shipped away for disposal could often be shipped in Type A packaging.

Type B Packaging [49 CFR Section 173.394(b)]

To ship any quantity greater than Type A of special form material, Type B packaging is required. Type B packaging is designed to withstand certain accident conditions without significant loss of shielding capability.

Type B packaging must pass these tests:

1. A 9.14 m (30 ft) drop onto a hard surface such as concrete.
2. A 101.6 cm (40 in.) drop onto a 15.24 cm (6 in.) diameter steel pin.
3. A fire of 1475 °F for 30 min.

The first two tests are illustrated in Figures 9.2 through 9.5. Figure 9.6 shows how a radiography camera survived an actual fire.

Most radiography cameras meet the requirements for Type B packaging. However, some cameras need additional packaging to meet the requirements for Type B packaging or to lower surface radiation dose rates. These cameras must be shipped in an *overpack.* An overpack is an outer package that the camera is put into for additional protection during shipping. Figures 9.2, 9.3 and 9.4 show a radiography camera in an overpack. Figure 9.7 is a 660B overpack. Figure 9.8 at right is an Industrial Nuclear IR-100 overpack.

No radiography source in Type B packaging has ever become unshielded because of a transportation accident. Type B packaging is designed to resist transportation accidents and does. Radiography sources in Type B packaging have not proven to be hazardous in transportation.

Radiation Limits for Packages

Even though the packages for transporting radiography sources contain shields, some gamma radiation will penetrate the package shielding.

In addition to the requirements on how the packaging is made, the Department of Transportation regulations have limits on the dose rate at the surface of a package and the dose rate at 1 m (39.37 in.) from the package. The dose rate limit at 1 m (39.37 in.) from a package is expressed in terms of a *transport index*. The transport index is the highest dose rate in mR/h at 1 m (39.37 in.) from the package. If the highest dose rate at 1 m (39.37 in.) is 5 mR/h, the transport index is 5. Figure 9.9 shows a worker measuring a transport index package.

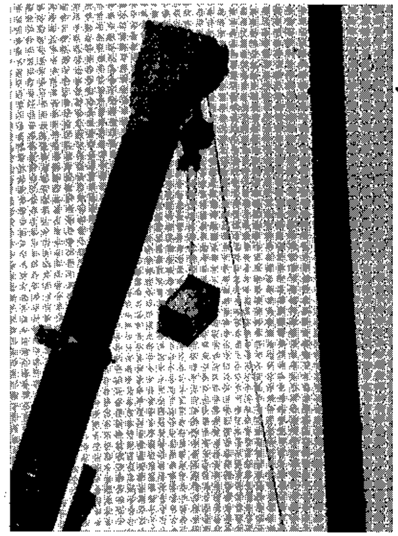


Figure 9.2: Radiography camera in an overpack being lifted for the 9.1 m (30 ft) drop test.

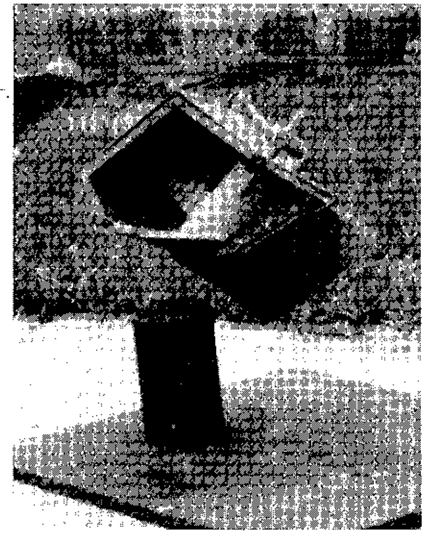


Figure 9.3: Impact of camera in overpack onto a steel cylinder.

Figure 9.4: Camera in an overpack after the impact. The source remained fully shielded.

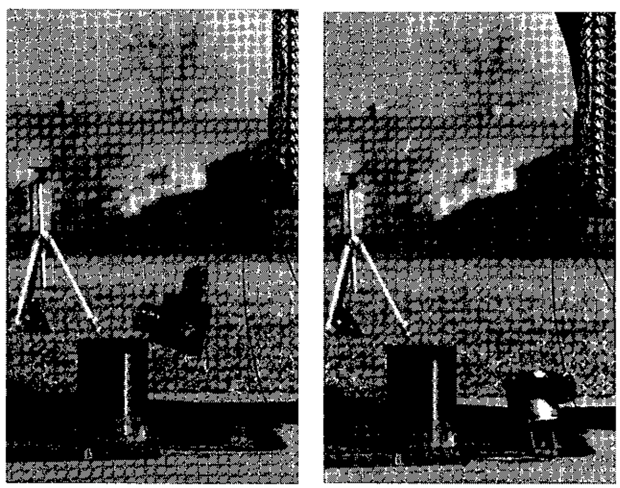


Figure 9.5: A 10.2 dm (40 in.) drop onto a 15.2 cm (6 in.) diameter steel cylinder. Photo on the left is the moment of impact, photo on right is immediately after impact.

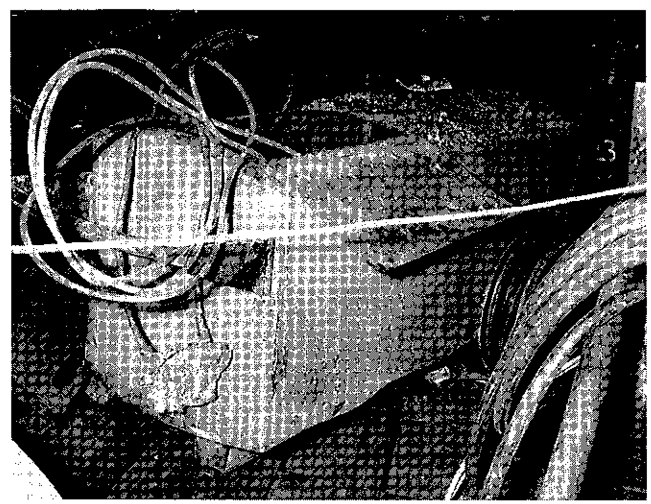


Figure 9.6: A fire in a factory destroyed this cobalt-60 camera. The tires burned off and the crank melted, but the shielding was undamaged. There was no radiation hazard.

Warning Labels

Packages containing radioactive materials must be labeled on two opposite sides with warning labels. These labels tell what radioactive material is in the package and the radiation dose rates near the package. There are three types of warning labels, depending on the dose rates.

If the surface dose rate is 0.005 mSv/h (0.5 mR/h) or less, *Radioactive White I* labels are used [49 CFR Section 172.436] (Figure 9.10).

Radioactive Yellow II labels are used if the surface dose rate does not exceed 0.5 mSv/h (50 mR/h) and the dose rate at 1 m (39.37 in.) (the transport index) does not exceed 0.01 mSv/h (1 mR/h) [49 CFR Section 172.438] (Figure 9.11).

Radioactive Yellow III labels, shown in Figure 9.12, are used for all packages with a surface dose rate greater than 0.5 mSv/h (50 mR/h) or dose rate at 1 m (39.37 in.) (transport index) greater than 0.01 mSv/h (1 mR/h) and less than 2 mSv/h (200 mR/h) on contact and 1.0 mSv/h (10 mR/h) at 1 m (39.37 in.). [49 CFR Section 172.440].

The dose rates for the three types of warning labels are summarized below [49 CFR Section 172.403] in Table 9.1 below.

For portable iridium-192 cameras with new sources, the dose rate at the surface usually exceeds 0.5 mSv/h (50 mR/h). Therefore, the camera will require the Radioactive Yellow III label while being shipped if no outer container is used. As the source decays, the dose rate at the surface will eventually drop below 0.5 mSv/h (50 mR/h) and a Radioactive Yellow II label would be acceptable. There is no need to worry about the exact moment when the transition occurs. However, as long as the Radioactive Yellow III label is used during transportation, all the precautions required for this label such as vehicle placarding are necessary.

Trucks carrying radiography sources often have special boxes that the camera is locked in. If the dose rate on the surface of the box is less than 0.5 mSv/h (50 mR/h) and is less than 0.01 mSv/h (1 mR/h) at 1 m (39.37 in.), a Radioactive Yellow II label can be used.

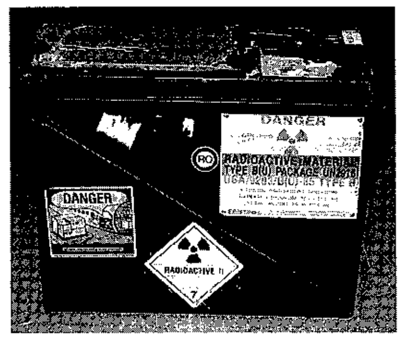
Cameras containing no source are still radioactive if they use uranium for shielding. Dose rates at the surface are about 0.005 mSv/h (0.5 mR/h). Department of Transportation

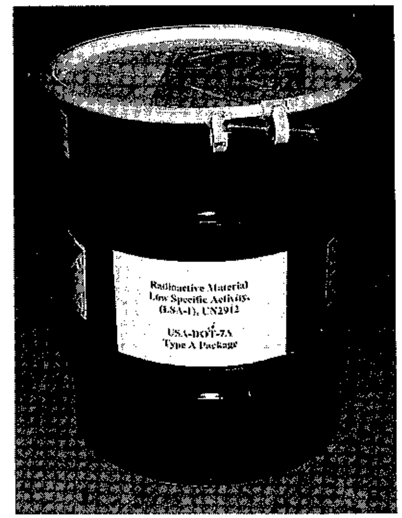
Table 9.1: Dose rates for the three types of warning labels.

Warning label	Maximum dose rate at the surface of the package	Maximum dose rate at 1 m (39.37 in.) from the package (transport index)
Radioactive White I	5 µSv/h (0.5 mR/h)	Nil
Radioactive Yellow II	500 µSv/h (50 mR/h)	10 µSv/h (1 mR/h)
Radioactive Yellow III	2 mSv/h (200 mR/h)	100 µSv/h (10 mR/h)

Figure 9.7: Below, 660B overpack.

Figure 9.8: At right, iridium 100 overpack.





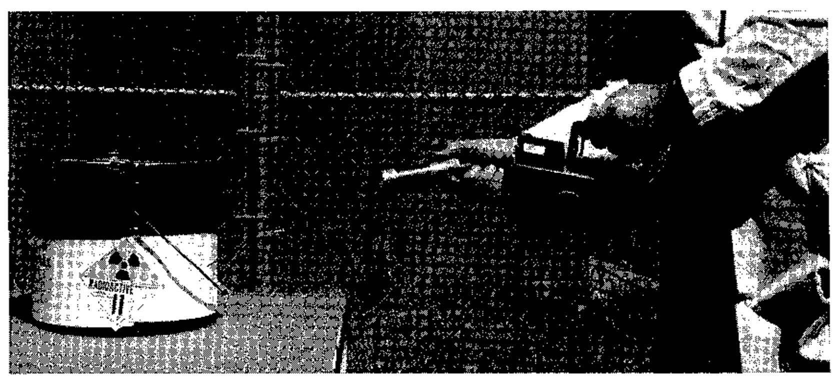


Figure 9.9: A worker measures the transport index of a package.

regulations [49 CFR Section 173.391(c)] exempt uranium from labeling if the surface dose rate on the package is below 0.005 mSv/h (0.5 mR/h). Therefore, either no label or the Radioactive Yellow II label may be appropriate depending on the dose rate.

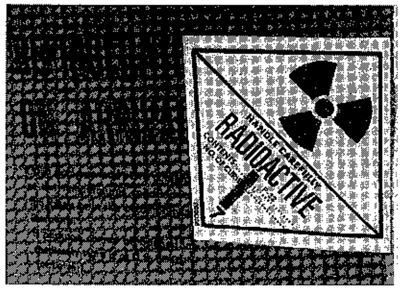


Figure 9.10: Radioactive White I warning label on a package.

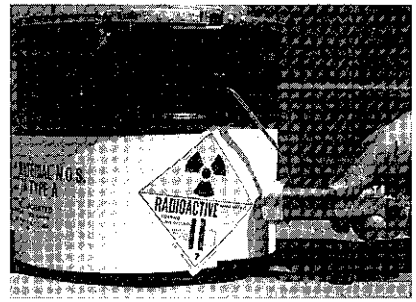


Figure 9.11: The surface dose rate on a package with a Radioactive Yellow II warning label is measured. A label on the left shows that this container meets the requirements for Type A packaging.

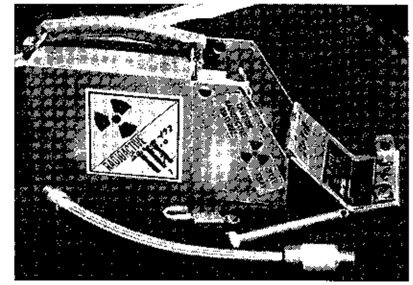


Figure 9.12: Radioactive Yellow III warning label on a source changer.

Moving the Source to the Work Site

If a package requires a Yellow III label, the vehicle in which it is carried must have *placards* [49 CFR Section 172.504]. A placard is a sign to show that the vehicle is carrying radioactive material. A truck with placards is shown in Figure 9.13. Placards must be put on all four sides of the vehicle. Vehicles carrying only White I or Yellow II labeled packages do not need placards.

Placarded trucks carrying radiography cameras should travel to the worksite by the quickest route [49 CFR Section 177.825(a)].[1]

The radiography cameras must be tied or braced against movement inside the truck to prevent the camera from falling out of the truck if the door is left open or some other mishap occurs [49 CFR Section 177.834]. If the camera is braced inside a box and the dose rate at the surface of the box is less than 0.5 mSv/h (50 mR/h) and less than 0.01 mSv/h (1 mR/h) at 1 m (39.37 in.), the box may use a Radioactive Yellow II label. Then no placards are needed on the truck nor are there special routing requirements. The box is best located near the rear of the truck to minimize the driver's radiation dose. A typical camera must be located at least 0.6 m (2 ft) from where the driver or passengers will be sitting [49 CFR Section 177.842(b)]. Transport index is assumed to be less than 0.05 mSv/h (5 mR/h) at 1 m (39.37 in.).

If the vehicle is left for some reason (for example, a coffee break), the camera must be locked inside to prevent it from being taken [10 CFR Section 20.207 and Section 34.23].

The radiation dose rate outside the truck should be measured. The dose rates allowed by Department of Transportation regulations outside the truck are higher than would be encountered

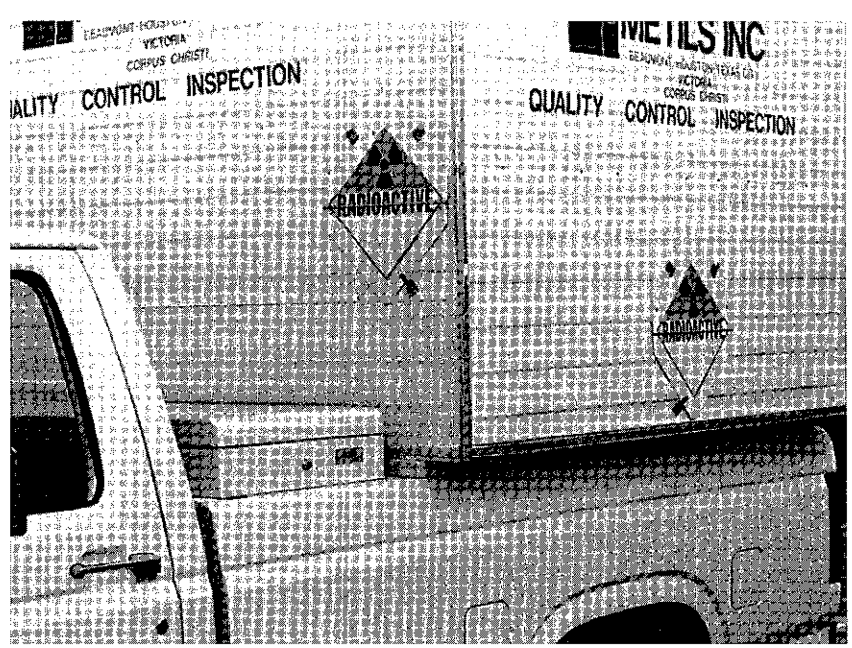


Figure 9.13: A truck with placards required by the Department of Transportation for trucks carrying packages with Radioactive Yellow III warning labels.

with a radiography source properly shielded within a camera. But if the truck will be used as a storage area when working in the field, the area outside the truck must meet Nuclear Regulatory Commission regulations for unrestricted areas. Dose rates in unrestricted areas must be below 0.02 mSv/h (2 mR/h) or 0.006 mSv/h (0.6 mR/h) if the truck will be in one place for a long time, to meet the 1.0 mSv (100 mrem) in 7 days limit. [10 CFR Section 20.105(b)].

A transportation checklist must be completed before starting the trip. Many employers combine this list with the source utilization log required by the Nuclear Regulatory Commission [10 CFR Section 34.27] because the information required for each is almost identical.

If involved in a traffic accident the radiographer should make an immediate radiation survey if at all possible. If radiation levels are above those expected, follow emergency procedures. The company may be required to report the accident to the United States Department of Transportation [49 CFR Section 177.861].

Receiving and Shipping Sources

Receiving a Source

Radiography sources shipped to a company must be picked up from the carrier promptly [10 CFR Section 20.205(a)]. This is to ensure the carrier's employees are not needlessly exposed to radiation by keeping the source and to reduce the risk that someone might take the source out of its shielding. It is usually assumed the radiography source requires Type B packaging and will be shipped by a common carrier in a vehicle that will carry many different packages from different shippers. The Department of Transportation calls this a *nonexclusive use vehicle.*

After the source is picked up from the carrier, a radiation survey must be made to verify levels do not exceed 2 mSv/h (200 mR/h) at the surface [10 CFR Section 20.205(c)]. A record of the survey must be made [10 CFR Section 20.401(b)]. Most companies will have a standard form for recording the receipt of a source. The form will usually ask for the source serial number, model number, isotope type and activity. It will also ask for the serial number and model number of the shipping container.

The dose rate must also be measured at 1 m (39.37 in.) [Section 20.205(c)]. The dose rate measured should be about the same as the transport index written on the package warning label. The dose rate at 1 m (39.37 in.) cannot exceed 0.1 mSv/h (10 mR/h). A record of this survey must also be made [10 CFR Section 20.401(b)].

Nuclear Regulatory Commission regulations do not require wipe tests for contamination for packages received that contain radiography sources because the sources are special form material [10 CFR Section 20.205(b)(1)(iii)].

If dose rates exceed 2.0 mSv/h (200 mR/h) at the surface or 0.1 mS/h (10 mR/h) at 1 m (39.37 in..), the company must immediately report this to the Nuclear Regulatory Commission and the carrier [10 CFR Section 20.205(c)(2)].

Shipping a Source

Before delivering a radiography source to a commercial carrier, the most important thing to do is to make sure the source is securely locked in the fully shielded position. To do this, make a radiation survey of the shipping container and by checking to see that the source is locked in the shielded position. This will prevent cargo handlers and others from being exposed to an intense beam of radiation from the source.

After the package has been surveyed and the lock is checked to verify the source is locked in the fully shielded position, attach a security seal with an identification mark on the package [49 CFR Section 173.393(b)]. The security seal informs the person receiving the package that the source has not been tampered with.

Apply the proper warning labels to two sides of the package [49 CFR Section 172.403(f)]. Most spent (used) sources will use a Radioactive Yellow II label because the surface dose rates will be less than 500 μSv/h (50 mR/h) and the dose rate at 1 m (39.37 in.) will be less than 10 μSv/h (1 mR/h). Remove any old warning labels from the package so that it does not have confusing or contradictory labels.

Mark the outside of the package: "Radioactive Material, Special Form, N.O.S." [49 CFR Section 172.300]. (N.O.S. means *not otherwise specified.*) If the package weighs more than 41 kg (110 lbs), write its weight on the package [49 CFR Section 172.310(a)].

If a shipping container is packaged inside a crate or other packaging, mark the outside package, "Inside container in accordance with ______" (insert DOT Specification Number or Type B Certificate Number). Also indicate the appropriate type of package, Type B or Type A [49 CFR Section 172.310] and [49 CFR Section 173.393(a)].

Fill out the shipping papers. This will include:

- Radioactive material, special form, N.O.S.
- Type of radioactive material (iridium-192 or cobalt-60)
- Special form
- Number of becquerels (curies)
- Type of warning label (such as Radioactive Yellow II)

- Transport index
- Nuclear Regulatory Commission identification number or Department of Transportation specification number.

The radiographer must also certify that the shipment is properly classified (such as Radioactive Yellow II), described, packaged, marked and labeled [49 CFR Section 172.204(a)].

For air shipment, radiography sources can only be shipped on cargo aircraft. Years ago radiography sources were permitted on passenger aircraft. In 1974, a radiography camera was shipped in a passenger aircraft with the source not fully shielded.[2] The receivers discovered and reported the condition, but the passengers and crew on the aircraft were exposed to radiation from the source. Because of this accident, Congress banned the shipment of radiography sources on passenger aircraft.

Air shipments must be labeled *Cargo Aircraft Only* [49 CFR Section 172.402(b)] and the shipping papers must state, "This shipment is within the limitations prescribed for cargo only aircraft."

Questions

1. Radiography sources are:
   a. special form radioactive material.
   b. normal form radioactive material.
   c. safe radioactive material.

2. The *transport index* refers to:
   a. the surface dose rate of a package containing radioactive material.
   b. the highest dose rate at 1 m (39.37 in.) from the surface of a package containing radioactive material.
   c. the dose rate at the surface of a truck carrying packages containing radioactive material.
   d. the dose rate in the driver's compartment of a truck carrying packages containing radioactive material.

3. The type of distinctive warning label that must be applied to the surface of a package containing radioactive material is determined by:
   a. the highest dose rate at the surface and at 1 m (39.37 in.) from the surface of the package.
   b. the weight of the material.
   c. the transport index.
   d. the type of vehicle in which the package will be shipped.

4. A Radioactive Yellow II warning label is applied to packages with a transport index of:
   a. 0.
   b. Between 0 and 1.
   c. Between 1 and 10.
   d. Between 10 and 100.

5. A package contains radioactive material. The highest dose rate at the surface is 250 μSv/h (25 mR/h) and the highest dose rate at 1 m (39.37 in.) from the surface is 25 μSv/h (2.5 mR/h). The proper radioactive warning label to apply on two opposite sides of the package would be:
   a. a Radioactive Yellow III label.
   b. a Radioactive Yellow II label.
   c. a Radioactive White I label.
   d. No label is required; the dose rate is too low.

6. Any vehicle carrying radioactive material must be placarded. True or False?

7. Any vehicle carrying a package containing radioactive material that has a Radioactive Yellow III warning label needs to be placarded on all four sides. True or False?

8. What are the basic steps that should be taken before transporting a radiography source?

Chapter 10

How Can Following Procedures Help the Radiographer?

The employer provides a set of specific operating and emergency procedures for performing radiography for the company. These procedures will vary from company to company to allow for the differences in the work performed and the needs of the company. It is very important to follow these procedures to avoid excessive exposure to radiation. Most overexposure accidents can be related to failure of the radiographer to follow procedures.

Operating Procedures

A great deal of this job is routine, hard work. Many may be tempted to take shortcuts. Don't. A company's operating procedures are the result of many years of experience in the radiography field. Every step is there for a reason. Radiation cannot be seen, heard or felt. If radiographers are not following a company's procedures, they may not know that something is wrong until it is too late.

A company's procedures are the commitment the company makes to safety. Sometimes these procedures may seem to be time consuming, but the company has carefully considered what steps are needed to work safely. The steps in the procedures have reasons behind them based on years of experience working with radiography sources.

Emergency Procedures

In an emergency situation, something has gone wrong in some unpredictable manner. The radiographer must act to eliminate any danger that exists and will have to make judgments, often quickly. To help make sound judgments in these unforeseen situations, the employer provides general rules on what to do. These are the emergency procedures. The employer is most familiar with the types of jobs performed and the equipment used. The employer also knows what training employees have had and what their capabilities are.

However, even these written emergency procedures are not likely to tell *exactly* how to handle a particular emergency. Emergency situations are just too unpredictable. For example, the Norfolk Naval Shipyard, as part of their training program, periodically held emergency drills. Their practical experience during these drills was that many situations contained some peculiarity that made it impossible or hazardous to follow their emergency procedures.[1] Sound judgment was usually necessary to improvise a procedure that would work safely in a particular situation. Because of this training, experienced radiographers have usually handled emergencies safely once they have been recognized.[2]

This book will not train a person in their own employer's specific emergency procedures, however, it does cover some general aspects of responding to emergencies.

Recognizing the Emergency

An emergency situation must be recognized before any suitable response can be made. Sometimes recognizing a problem is easy. If a radiographer sees the source guide tube crushed by a piece of heavy equipment and the source cannot be retracted, it is obvious there is a problem.

Sometimes emergencies may not be immediately recognized. A source can disconnect in the guide tube without the radiographer's knowledge. Illness or fatigue may impair a person's ability to work properly. Serious distractions can cause confusion and lead to errors, such as shown in Figure 10.1.

The first step is to recognize that a dangerous situation exists, to recognize conditions are a *warning sign*. These will provide a signal that there could be a dangerous situation. By learning what situations have caused accidents in the past, radiographers may be able to avoid an accident when in a similar situation. In the next chapter, accidents that started without the radiographer knowing that anything was going wrong will be discussed.

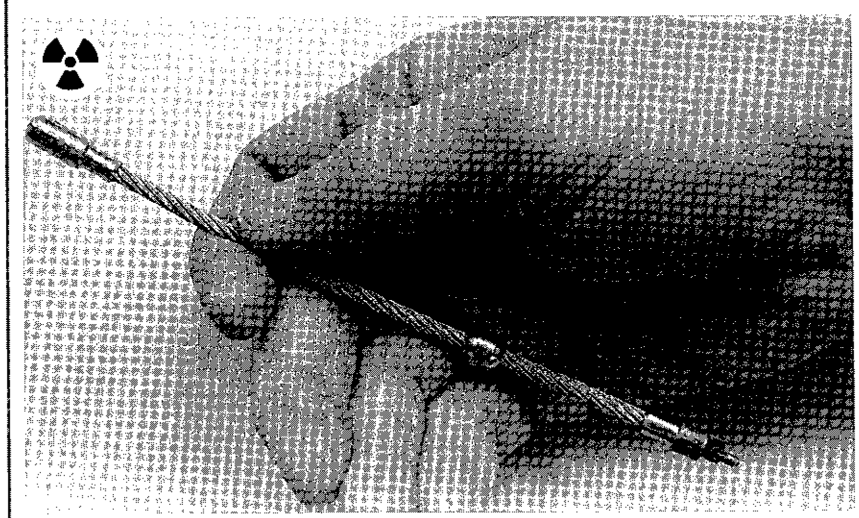


Figure 10.1: The worst thing you can do is hold a source like this. The dose rate on the surface of the source capsule can cause radiation burns in seconds. Of course, a dummy source was used for this picture.

Immediate Response

What should be done if a source is exposed? Once it is recognized that an emergency exists, there is usually plenty of time to make a correct judgment.

First, move away from the exposed source and keep other people away. Just a few yards reduces radiation levels considerably. For a 3.7 TBq (100 Ci) iridium-192 source, moving just 3.0 m or 4.6 m (10 ft or 15 ft) away reduces the radiation level to roughly 40 mSv/h (4 rem/h). The worst thing to do is to touch the source with a hand. Don't try to put the source back into the camera by hand or reconnect it to the drive cable by hand. Touching a 3.7 TBq (100 Ci) iridium-192 source causes radiation burns in seconds.

Second, relax, remain calm, think and don't panic. When a few yards away from the source, there is time to think about what to do. Don't panic if the source cannot be immediately shielded.

Third, establish a restricted area and make sure no one approaches the source. Rope off the area, if possible, if this has not already been done. Use the survey meter to ensure the restricted area has been properly roped off.

Fourth, call for help, but don't leave an exposed source unattended. If there is no one there to help, remain in the area if possible, but not too close to the source. Sooner or later someone will come along. *A radiographer should not try to do anything he is not trained to do.*

1. Move away from the source at once.
2. Calm down and think.
3. Establish restricted area.
4. Call for help.

For any emergency, it is important to know who to call for help. A common requirement of emergency procedures is to contact the employer's radiation safety officer

If the police are contacted, it is important to provide as much information and assistance as possible. The radiographer will usually have the most knowledge of the situation and will be a key person for others to talk to.

Discussion

The situations below are meant to be discussed in a class of people training to be radiographers. In most instances, students will have to invent additional information to fully describe the situations. There are many different ways to handle these situations safely.

1. You are at your lunch break when another radiographer approaches and asks to use your film badge. He says he has to make some exposures and does not have his with him. Discuss what you would do.

2. You are a radiographer's assistant in training at a field site under the supervision of an experienced radiographer. After a few exposures, you notice that your dosimeter reads about half scale, about 25.8 μC (100 mR), and you bring that to the attention of the radiographer. He assures you that there is no problem and tells you to get back to work. Discuss what you should do.

3. You are setting up an exposure at a site when you discover that your survey meter is not working. This is a common radiography shot that you have performed many times in your career as a radiographer. Should you go ahead with the shot, based on previous experience, or not? Discuss how you would handle this situation.

4. You have just finished an exposure and are trying to retract the source when you realize that it is stuck. Discuss what you would do.

5. You are working in a permanent radiography cell equipped with a radiation alarm. The alarm goes off with no source being exposed and you are able to determine that the alarm is malfunctioning. There is no one on site available at this time to repair the alarm so you are left with two options: (a) turn the power to the alarm off and continue your work using your survey meter, or (b) don't take any more shots until the alarm has been repaired. What would you do?

6. It is early afternoon. You have just charged your pocket dosimeter and are setting up for a shot. You take a survey before the exposure of the source and your survey meter shows everything is fine. But when you check your dosimeter, it reads off scale. Would you assume your dosimeter is malfunctioning and proceed with the shot? Or would you assume your survey meter is inoperable and try to get another one before completing the shot? What would you do?

7. You are working by yourself. In the middle of a shot, you get dizzy and collapse. A few minutes later you feel somewhat better. Should you continue your work?

8. A crane has just rolled over the crank of your camera while the source is out. The crank assembly looks like the one in Figure 10.2. What do you do?

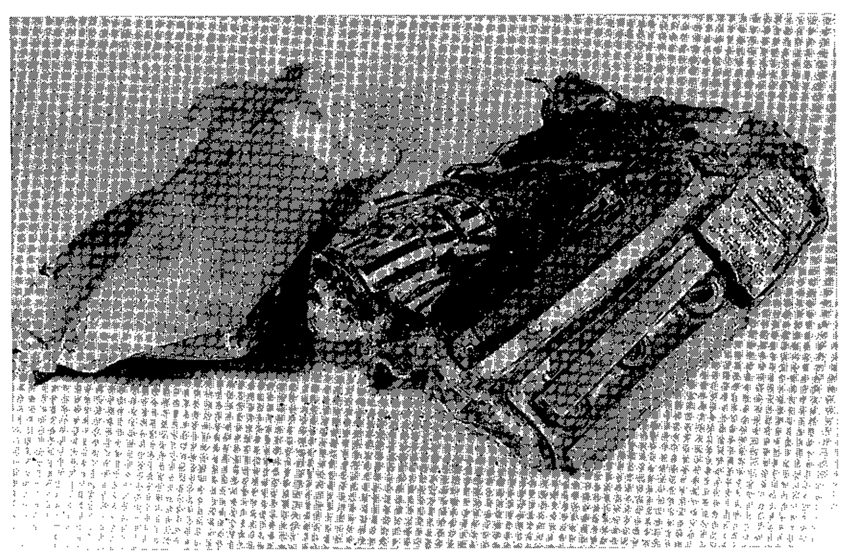


Figure 10.2: A crank assembly that was run over by a crane.

Chapter 11

Why Do Radiography Accidents Happen?

Throughout this book radiation overexposures and how to avoid them has been discussed. Why is there so much concern about overexposure accidents?

The reason is that industrial radiographers suffer a major portion of the overexposures among workers employed by Nuclear Regulatory Commission licensees. For example, in the 10 year period from 1971 to 1980 about 600 overexposures were reported by all NRC licensees. (See Appendix D, Table 1.) Of these, about 25% were received by radiographers even though they make up only a small percentage of the people working with radiation at NRC licensed activities.

The figures for serious overexposures are even more striking. We consider a serious overexposure to be a dose greater than 250 mSv (25 rem) given to the entire body or over 3.75 Sv (375 rem) to a portion of the body such as the hands. These doses are just below the dose levels where physical symptoms would be evident shortly after the overexposure. During the 10 years from 1971 to 1980, there were 21 overexposures reported that exceeded these doses. Of these, 15 were received by radiographers. This means radiographers suffered over 70% of the most serious overexposures reported by Nuclear Regulatory Commission licensees. A few of these serious overexposures caused permanent harm to the people exposed.

This is not to say that the record of gamma radiography is poor. Radiography sources are potentially very dangerous. They are used tens of millions of times a year by thousands of people. In comparison to the opportunities for accidents, the accidents are very rare. Still, severe overexposure accidents sometimes do happen.

How Radiography Accidents Happen

Radiography accidents usually happen because of the following failures. First, the radiographer does not return the source to the fully shielded position leaving the source exposed. Second, the radiographer omits the radiation survey or does not survey adequately. Third, in some cases, the radiographer does not follow the company operating and emergency procedures or take short cuts.

A Source Is Left Exposed

Why are sources left exposed when they should not be? To answer this question we looked at the 48 most serious radiography accidents reported to the Nuclear Regulatory Commission from 1971 to 1980. The accidents are listed in Appendix D, Table 2.

The most common event was having the source near the entrance to the S-tube of the camera (Figure 11.1). This happened in about one quarter of the accidents. Why this happened is not clear though it is easy to list several possibilities.

- The source was caught or hung up on the joint between the guide tube and the camera.
- The source was fully cranked in but the crank handle jumped back half a turn after the ballstop hit its stop.
- Tension in the control cables in some way caused the source to be pushed out.
- A sharp bend in the guide tube near the camera caused the source to get stuck.

The second most common event was forgetting to retract the source. From what is known about how frequently humans make an error, such as omitting one step in a process, the performance of radiographers in remembering to retract the source is quite good. Because of the serious consequences, this type of accident is still of concern.

The third most common event is the source jamming somewhere in the guide tube. This can happen if some heavy object crushes the guide tube or if the guide tube is bent too sharply. Rigid guide tubes (used for special purposes) can kink when bent and the kinks have caused sources to jam.

In three of the 48 accidents, a source disconnected from the control cable. This can happen if

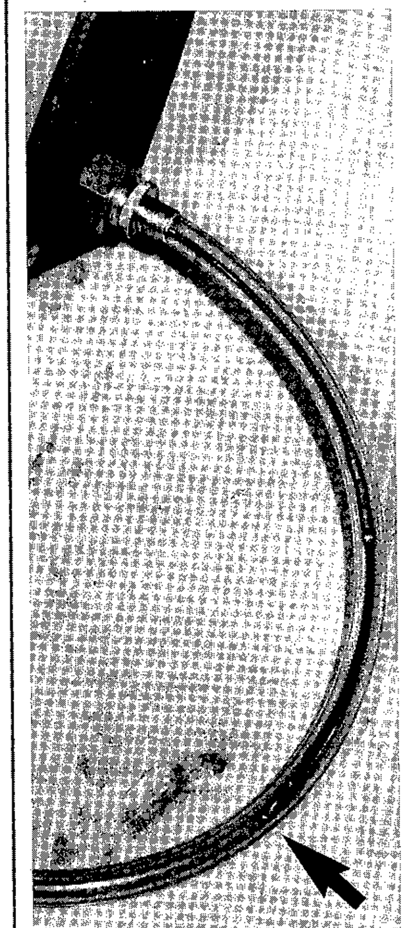


Figure 11.1: A dummy camera with transparent sides and guide tube is used here to show the position of an incompletely retracted source. The arrow shows the location of a source near the entrance to the S-tube. While disconnecting the guide tube, you can experience a particularly severe overexposure to your hands because they will be so close to the source.

the source is not connected properly from the beginning, if the cable breaks or if the connector is worn.

In three cases at permanent radiographic installations, two sets of controls for two sources were present. Instead of cranking in the source they were working with, the radiographers cranked *out* the other source, leaving two sources exposed. The radiographers conducted surveys but could not understand why cranking the sources in and out did not lower the radiation level. They assumed the survey meter was broken and continued their work. Overexposures resulted.

In other situations radiographers have confused *in* and *out* while fatigued or distracted. In a few cases, sources have been intentionally exposed by disgruntled workers.

The Omitted Survey

An exposed source will be discovered quickly if the required radiation survey is done and done properly. If the exposed source is detected, an overexposure is unlikely. But in about half of the serious overexposures reported to the Nuclear Regulatory Commission between 1971 and 1980, no radiation survey was attempted. (See Appendix D, Table 2.) It is difficult to know exactly how often radiographers omit surveys. It is estimated that radiographers survey 80% to 90% of the time after the source is retracted.[1] Radiography overexposures usually happen during the 10% to 20% of the time that surveys are not made or are not made correctly.

Overexposures can still happen if surveys are not conducted properly. This is easy to do if the source is located at the entrance to the S-tube in the camera. When the camera is approached from the back, radiation levels will be near normal because the shielding in the camera will shield the radiation.

Similarly, a survey meter left on the ground next to the camera may not detect a source at the entrance of the S-tube. Radiographers who do not survey the front of the camera may not discover a source at the entrance of the S-tube.

Broken survey meters contributed to two of the overexposures. At times, a 0 reading has led the radiographer to mistakenly think that the source was in its shield. A survey meter should *not* read 0 near the side of a camera. A radiographer should know what to do if he gets an unusual reading like this on the survey meter.

There have been overexposures where the radiographers thought the survey meter was malfunctioning because it was reading too high, but in reality the source was exposed. As many overexposures have occurred when the radiographer *did not believe* a high reading on the survey meter as when a meter was broken.

Most radiographers know what to do in normal situations. Difficulty arises, however, when unusual or unexpected things happen. How to check a survey meter in the field if it starts to behave abnormally was addressed in a previous chapter. Although abnormal survey meter readings don't happen very often, the radiographer should be prepared to deal with an unusual situation. A person's safety may depend on how well an unexpected situation is handled.

Not Locking the Camera

Many cameras in use today cannot be locked unless the source is in the fully shielded position (Figure 11.2). First, crank in the source, noticing whether the feel of the cranking is normal. Second, try to expose the source to make sure that the source is captured by the automatic securing system. Third, use a survey meter to ensure that the source is properly shielded.

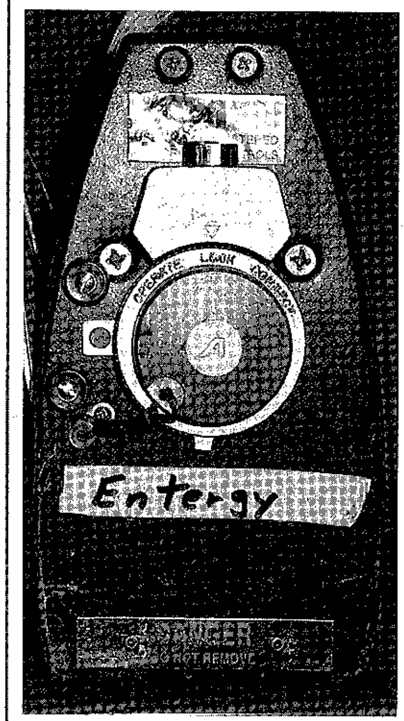
But Why?

So far this book has discussed what happens, but not why. *Why* does a radiographer forget to retract a source? *Why* doesn't a radiographer survey? *Why* doesn't a radiographer lock in the source?

In many accidents, it is not possible to answer these questions. The reports written about radiography accidents often do not deal with the radiographer's motivations because they cannot be positively known. Often the radiographer really does not know or will not tell. But by looking at accidents and by drawing on experience, it is possible to put together a picture of why radiography accidents happen.

Equipment failure is not often a factor in accidents. Considering

Figure 11.2: You cannot rotate the locking ring on this camera to lock it if the source is not in the fully shielded position.



the 48 accidents mentioned earlier, there did not seem to be *any* cases where a camera that was properly operated and maintained had failed. In the majority of cases, there was no equipment failure at all. In no case did equipment failure cause an overexposure itself without some errors on the part of the radiographer. Even in those situations where there was some equipment failure, the failure could be traced to an error on the part of the radiographer in operating the equipment, or the equipment was not properly maintained or repaired. In short, equipment failures do not play a leading role in radiography overexposures.

Poor training is often blamed for radiography accidents. If an accident happens when a radiographer does not survey, this is sometimes seen as a training failure. However, sending the radiographer for refresher training on the importance of making surveys may not be the answer. In the 48 accidents studied, it was rare for the radiographer to be completely untrained. In some cases, however, the radiographer did not react properly to unusual situations. Overall, better training, especially on dealing with unusual situations, would have reduced the number of overexposure accidents. Usually there were other factors involved as well.

A Case History

Reviewing case histories may help answer some questions. The factory worker in California who received a radiation burn from a source left behind by a radiographer (Chapter 4) is a good example.

The radiographer involved had 32 years of experience, had an excellent record and was the radiation safety officer for his company. How did he end up dropping a source and leaving it behind? Though he does not say, a review of some of the things that were involved may help answer the question. A doctor who examined the radiographer after the accident found he had severe anemia. The doctor thought the condition to be so severe that the man could not perform reliably. The radiographer disagreed, saying he felt fine.

The radiographer was working in a shop during lunch hour, but the work was taking longer than expected. The shop workers had finished lunch and were banging on the door, shouting to be let in. The radiographer attempted to disconnect the control cable from the source and disconnect the guide tube at the same time. To disconnect the source pigtail, he had to crank out the drive cable to enable the drive cable connector to clear the sheath.

Working quickly, he probably cranked the source assembly out of the camera after the guide tube had been removed. The source assembly was attached with a hook-and-eye connector (Figure 11.3). Once out of the camera, the assembly was free to swing down and drop off. Because he was working quickly and using only one hand to disconnect the source, he probably did not notice that the source was already disconnected from the drive cable.

The radiographer says he conducted a survey, but if he did, he did not pay attention to what the survey meter was telling him.

Hours later the radiographer returned to the shop after he had been called and told he had left something behind. The radiographer told the shop workers that the source they had found was not radioactive and not dangerous.

Why did the radiographer make these mistakes? Perhaps a combination of poor health and being hurried by the workers caused the radiographer to rush, become distracted and not pay attention to what he was doing.

Some Other Examples

In Massachusetts a radiographer became sick at work. He stopped working, loaded the camera into his truck without making a survey and drove home. The next day he discovered he had left the source exposed.

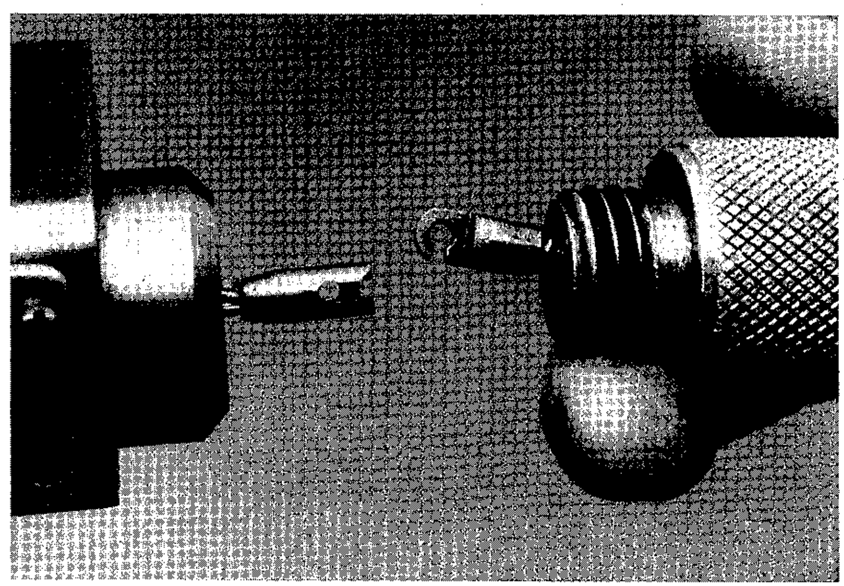


Figure 11.3: The hook and eye connector in the California case.

Radiation burns on the hands of a radiographer (Chapter 4) were caused when that radiographer confused *in* with *out*. The source was out whenever he moved the guide tube. In addition, the radiographer did not make a survey. This reversal error is a common error, but why did he make these mistakes? In this case, the radiographer was working at night, was tired and was in a hurry.

In Virginia, an experienced radiographer with an excellent safety record went to work overtime on Sunday morning. The radiographer propped open the door to the exposure room because the room was too hot, but to do this he had to disconnect the alarm system. He did his work without a film badge or pocket dosimeter and without making surveys. He forgot to retract the source after an exposure and was overexposed. A company manager concluded that the man was probably distracted because his wife was in the hospital giving birth to a baby in a difficult delivery at that time.

In another case, work was being performed just after midnight. The work load that week had been heavy and things were hectic at times. The radiographer was paged on the intercom, but he wanted to complete the shot before responding. The radiographer was paged again and this time recognized that the call was from his supervisor. Assuming there was a problem with his earlier shots he went to take the call. In his hurry he did not survey carefully and twisted the camera locking ring, but not sufficiently. The assistant radiographer was exposed.

The Human Factor

Overall, what can we conclude? Overexposures happen when the source is left out and a radiation survey is not made or is made incorrectly. Occasionally equipment does not operate as expected. Occasionally the people involved are not sufficiently trained, especially for dealing with an unusual situation, but usually their training is reasonably adequate.

These accidents seem to happen when the radiographer is under stress or cannot concentrate on his work. The reason may be that he is tired, sick, worried about something, in a great hurry or thinking about other things. Many studies have shown that accidents are more probable after violent quarrels or after family trouble or stress.

Be alert to the known warning signs of too much stress that can lead to mistakes and accidents: irritability, hyperexcitation, depression, excessive drinking, pounding of the heart, impulsiveness, the urge to cry or run and hide, inability to concentrate, feeling of unreality, fatigue, fear of nothing in particular, trembling or nervous tics, high pitched nervous laughter, insomnia, inability to sit still, nightmares and being accident prone.

Too little stress can also lead to accidents. If people are either not stimulated or overly stimulated, their performance is likely to suffer and more accidents will result. If a job is going at an unusually slow pace, if a radiographer is unusually sleepy, or if there is little incentive for production, alertness will be low and performance may be impaired.

These are the personal factors so often involved when an accident happens.

When under stress or unable concentrate, try to change the situation. Take a break or ask the supervisor and coworkers for help. Recognize any unusual circumstances that might cause an accident. Then, take special care to follow correct procedures.

Remember also that a radiographer will believe what he wants to believe. At the times when a radiographer least wants the source to be out, he will ignore the signs that it is out. This is seen in case after case. A worker hears an alarm and assumes that the alarm is malfunctioning rather than that the source is exposed. A high meter reading is taken to mean that the meter is malfunctioning. Audible alarm dosimeters are not heard. Failure to be able to turn a locking ring means the locking ring is broken. If any of these events occurs, expect the worst. Until the situation is under control, the radiographer is in danger of an overexposure to radiation.

Think about the case of a radiographer working in wet fly ash. The survey meter needle read off scale, but an audible speaker was silent. He cranked and recranked the source as hard as he could, but could not lock the camera. He concluded that the wet fly ash had shorted the survey meter causing the needle to go off scale and had jammed the locking mechanism. Actually, the meter and locking mechanism were working. The wet fly ash had jammed the crank, preventing the source's full return into the camera and had shorted out the audible speaker. We all believe what we want to believe.

When the last thing in the world that the radiographer wants to think about is the source, that's when the accident is going to happen.

Discussion

In this book, the radiographer's responsibility to protect himself and others from being exposed to a radiography source has been discussed.

1. In what ways do you think this is *your* responsibility?

2. How well do you think you can handle this responsibility?

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* Letter of Intent received from Governor to become an Agreement State.

(Last major update: 26 Mar03)

Appendix B
Nuclear Regulatory Commission Regional Offices

Additional Nuclear Regulatory Commission contact information can be found at the NRC Web site <www.nrc.gov>.

Region I Location

U.S. NRC Region I
475 Allendale Road
King of Prussia, PA 19406-1415
PH: (610) 337-5000
800-432-1156
7 am to 4:15 pm (ET),
Monday through Friday
TDD: 301-415-5575

Region II Location

U.S. NRC Region II
Sam Nunn Atlanta Federal Center,
23 T85
61 Forsyth Street, SW
Atlanta, GA 30303-8931
PH: (404) 562-4400
800-577-8510
7 am to 4:15 pm (ET),
Monday through Friday
TDD: (301) 415-5575

Region III Location

U.S. NRC Region III
2443 Warrenville Road
Suite 210
Lisle, Illinois 60532-4351
PH: (630) 829-9500
800-522-3025
7 am to 4:45 pm (CT),
Monday through Friday
FX: (630)515-1078
TDD: (301) 415-5575

Region IV Location

U.S. NRC Region IV
Texas Health Resources Tower
611 Ryan Plaza, Suite 400
Arlington, TX 76011-4005
PH: (817) 860-8100
800-952-9677
7:30 am to 4:15 pm (CT),
Monday through Friday
TDD: (301) 415-5575

Contact a Public Affairs Officer

Contact a Nuclear Regulatory Commission Public Affairs Officer at the following telephone numbers.

Headquarters:
PH: (301)415-8200
800-368-5642
TDD: (301) 415-5575
FX: (301) 415-2234
Sue F. Gagner, Robert J. Jasinski, Scott R. Burnell or David R. McIntyre

Region I (Philadelphia):
PH: (610)337-5330
Diane Screnci, Neil A. Sheehan

Region II (Atlanta)
PH: (404) 562-4416
Ken Clark, Roger Hannah

Region III (Chicago):
PH: (630) 829-9663
Jan Strasma, Viktoria Mitlyng

Region IV (Dallas):
PH: (817) 860-8128
Victor L. Dricks

Regulations and Forms

NRC Regulations and Forms NRC-4, NRC-5 and NRC-241 can be obtained from the NRC Web site <www.nrc.gov>.

Appendix C
Glossary

This glossary contains terms as they are used in gamma radiography. Some terms in this glossary have not been used in the text. They are included for your information.

absorbed dose – A highly technical term meaning the radiation dose or amount of radiation that has been absorbed by some substance. In the SI system, the unit for radiation absorbed dose is the *gray* (Gy). The older unit is the *rad*.

activity – A measure of the strength of a radioactive source. In the SI system, activity is measured in units of *becquerel*. The older unit is the *curie*.

acute radiation exposure – Exposure to a large dose of radiation in a short period of time. In radiography, this usually refers to the dose a person receives from coming very near a source.

acute radiation syndrome – The medical term for *radiation sickness*.

Agreement State – A state that has signed an agreement with the Nuclear Regulatory Commission allowing the state to regulate certain activities using radioactive materials, for example, gamma radiography using iridium-192 or cobalt-60 sources.

alpha particle (alpha ray, alpha radiation) – A small electrically charged particle of ionizing radiation thrown off by some radioactive materials. Alpha particles have a short range and cannot penetrate the outer dead layer of human skin. But, if radioactive materials emitting alpha particles are inhaled or swallowed, they can be very dangerous.

ASNT – American Society for Nondestructive Testing: a professional organization concerned with nondestructive testing, including industrial radiography.

atom – A unit of matter. An atom consists of a central charged nucleus (made up of neutrons and protons) and electrons that surround the nucleus.

attenuation – The reduction in the intensity of radiation as it passes through any material, for example, through lead shielding.

audible alarm dosimeter – Small electronic instrument that a person can wear and will sound an alarm when a high radiation dose rate is encountered or when a certain radiation dose has been exceeded. Sometimes called *alarming pocket dosimeter* or *electronic pocket dosimeter*.

autoradiograph – Radiograph of an object made by using the radiation that comes from the object itself without using any other radiation source.

background radiation (natural) – Radiation that is emitted from the naturally occurring radioactive materials in the Earth and from cosmic rays that bombard the Earth from outer space.

ballstop – A ball attached to the pigtail of a radiography source that prevents the source from being pulled out the back of the camera.

battery check – A check to see that the batteries of a radiation survey meter are strong enough. Generally, a *battery-check button* is pushed and a needle moves to show if the batteries are strong enough.

Becquerel, Henri – The French scientist who first discovered a naturally occurring radioactive material, uranium, in 1896.

becquerel (Bq) – SI unit for measurement of radioactivity, equivalent to one disintegration per second. Replaces *curie*.

BEIR Committee – Biological Effects of Ionizing Radiation Committee of the National Academy of Sciences. This committee is composed of a group of eminent scientists from throughout the United States who report to the Academy on the health effects of radiation.

beta particle (beta ray, beta radiation) – An electrically charged particle of radiation emitted by many radioactive materials. A beta particle is a fast moving electron, sometimes moving close to the speed of light.

bill of lading – A document accompanying a shipment of goods that lists the contents of the shipment.

Bq – Becquerel.

byproduct material – Radioactive material, such as cobalt-60 or iridium-192, obtained as a byproduct of running nuclear reactors or making nuclear fuel.

C – Coulomb.

calibration – Adjustment of a radiation survey meter to make it read a radiation dose accurately. A radiation source must be used for proper calibration.

camera, beam type – A radiography camera where the radioactive source never leaves the camera. The source is exposed by moving it in front of an opening or by moving a piece of shielding away from the front of the source.

camera, crank out – A radiography camera where the source is cranked or pushed out of the shield to make the radiography exposure.

camera, fixed – A radiography camera that is not movable.

camera, mobile – A radiography camera that can be moved by pushing it on wheels.

camera, pipeline – A beam type radiography camera especially made for radiographs of pipelines. Often called a *pipeliner*.

camera, portable – A radiography camera that can be carried by hand.

camera, radiography (or gamma radiography camera) – A container with a shield inside to hold a gamma radiography source. A means is provided to move the source outside the shield or remove part of the shield to make radiographs. It is called a *camera* because it is used to take pictures (radiographs). Also called a *radiography exposure device* or *radiographic exposure device*.

cancer – A disease in which rapidly multiplying cells grow in the body, interfering with its natural functions. Ionizing radiation may increase the probability that a person will get cancer.

capsule, radiography source – The small sealed metal capsule containing the radioactive materials that emit the gamma rays used in gamma radiography.

cassette – The covering that radiography film is placed in to prevent light from striking the film.

cataract – A medical term for the loss of transparency of the lens of the eye.

cell, radiography – A shielded room in which radiography exposures are made. Called a *permanent radiographic installation* in Nuclear Regulatory Commission regulations. Also called an *exposure cell*.

cesium-137 – A radioactive material sometimes used in radiography. An isotope of the element cesium. It emits gamma rays with an energy of 0.662 MeV and has a half life of 30 years. Symbols: Cs-137, ^{137}Cs, Cs^{137}.

CFR – See *Code of Federal Regulations*.

chirper – An electronic dosimeter that *chirps* or *beeps* periodically in the presence of radiation. It is a type of audible alarm dosimeter. It chirps faster when the dose rate increases.

chromosome – All the genetic material or genes contained in a living cell. Chromosomes control the reproduction of cells and the characteristics of the cells produced from the original cell. See *gene*.

cobalt-60 – A radioactive material used in radiography, noted for very penetrating gamma rays. An isotope of the element cobalt. It emits gamma rays of energy 1.17 MeV and 1.33 MeV. It has a half life of 5.3 years. Symbols: Co-60, ^{60}Co, Co^{60}.

Code of Federal Regulations (CFR) – The volume of books containing the regulations issued by federal agencies.

collimator – A small radiation shield of lead or other heavy metal used in radiography. A collimator is placed on the end of the guide tube and has a small opening through which a narrow cone of radiation escapes when the source is cranked into position. Use of a collimator can greatly reduce the size of the area to which access must be restricted.

contamination, radioactive – The presence of radioactive material spread on surfaces where it is not supposed to be.

control cable – Means the same as *drive cable.*

cosmic radiation – Ionizing radiation that comes from outer space. See *background radiation, natural.*

coulomb (C) – SI unit for electric charge, replacing faraday and ampere hour. X-ray or gamma ray intensity is measured in coulomb per kilogram (C/kg).

coupon, test – A test sample of a welder's work. The coupon will be radiographed to determine whether the welder is qualified for the welding job.

crank or crank handle – The handle used to crank the source in or out in a crank out camera.

crank out camera or device – See *camera, crank out.*

curie – A basic unit to describe the intensity (strength) of radioactivity in a material. A curie is a measure of the rate at which a radioactive material throws off particles or disintegrates – 1 Ci is equal to 37 billion disintegrations per second. In SI units, 1 Ci is equal to 37 GBq.

Curie, Marie and Pierre – The French scientists who discovered radium in 1898 and made possible the start of gamma radiography.

decay constant – A numerical constant that expresses the rate at which radioactive materials decay.

decay curve – A graph showing the decreasing radioactivity of a radioactive source as time passes. The term can also refer to the line or curve on the graph that indicates the activity.

decay, exponential – A mathematical expression to describe the rate at which a radioactive material decays.

decay, logarithmic – The same as *exponential decay.*

decay, radioactive – The breaking up or disintegration of atoms that have excess energy. Radiation is emitted in the process.

delayed effects – Those effects caused by radiation that do not become evident until years after exposure to radiation. The possible delayed effects of radiation are cancer in the exposed persons and genetic defects in their offspring.

densitometer – An instrument used to read how dark a piece of film is.

depleted uranium – Uranium having a smaller percentage of uranium-235 than that found in uranium as it occurs naturally. Depleted uranium is an excellent shielding material.

detector, gas filled – A radiation detector filled with gas. It detects ions formed by radiation.

detector, radiation – The part of a radiation survey meter that is sensitive to radiation.

disintegration – The breaking up of an unstable atom. Radiation is emitted in the process. See *decay, radioactive,* and *curie.*

DNA – Deoxyribonucleic acid. The long spiral molecules found in all living cells that control cell functioning and reproduction. Radiation injury is the result of damage to these molecules.

dose – Dose is the amount of radiation absorbed by an object. In SI units, dose can be expressed in *sieverts*. The older units are *roentgen, rem* or *rad.*

dose equivalent – A highly technical term referring to radiation dose expressed in SI units of *sievert* or older units of *rem.*

dose rate – A measure of how fast a radiation dose is being received. It is a dose per unit of time. For example, "The dose rate is 0.1 millisievert (10 millirem) per hour."

dosimeter – A device used to determine the radiation dose a person has received. See *dosimeter, pocket; film badge;* and *dosimeter, thermoluminescent.*

dosimeter, pocket – A small air filled ionization chamber (about the size and shape of a cigar) that measures radiation dose by responding to ionization in the air.

dosimeter, thermoluminescent – A dosimeter worn by a person to measure radiation dose. It contains a radiation sensitive crystal that responds to radiation like the film in a film badge.

DOT – United States Department of Transportation. A federal agency that regulates the transport of radioactive materials.

drive cable – A cable used to push a source out of a crank out camera. Usually operates with a crank. Also called a *control cable.*

electromagnetic radiation – See *radiation, electromagnetic* or *waves.*

electron – A very light particle that rotates around the nucleus of an atom and carries a negative electric charge. Electricity is the flow of electrons.

electron volt – A small unit of energy. The energy of X-rays and gamma rays is often given in units of electron volts. Abbreviations: eV - electron volts; KeV - thousand electron volts; MeV - million electron volts.

element – A basic type of matter. Each element has distinct chemical properties. There are 92 different elements that are found in nature, for example, hydrogen, oxygen, lead, uranium, carbon, tungsten and iron.

empty label – A Department of Transportation label used when a container normally used for transporting radioactive material does not contain any radioactive material.

erythema – A medical term for a reddening of the skin caused by increased local circulation of blood as a reaction to tissue injury. It can be caused by very large doses of radiation.

exclusive use vehicle – A vehicle that carries no cargo other than a shipment of radioactive material.

exponential decay – See *decay, exponential.*

exposure – Being exposed to radiation. People can be exposed to a radiation dose, or a film can receive an exposure to radiation. In radiography, an *exposure* or *shot* is the making of a radiograph. Exposure is also a highly technical term meaning the amount of ionization in air caused by X-rays or gamma rays, which is measured in SI units of *sievert* or older units of *roentgen.*

exposure device, radiographic – The term used in Nuclear Regulatory Commission regulations to mean a *radiography camera.*

fallout, radioactive – Radioactive debris from the explosion of nuclear weapons that falls out of the atmosphere onto the Earth.

film badge – A dosimeter badge worn by radiation workers to measure their radiation dose. The badge contains a piece of film that is darkened by radiation. The radiation dose can be determined by reading how dark the film is.

gamma alarm – A radiation detector that sounds an alarm when it detects excessive gamma ray or X-ray radiation.

gamma radiography – See *radiography, gamma.*

gamma rays (gamma radiation) – A type of penetrating and ionizing radiation used in industrial radiography. Gamma rays are similar to X-rays but come from the nucleus of an atom when it decays.

gas filled detector – See *detector, gas filled.*

geiger counter (geiger-mueller counter, G-M counter, G-M tube) – An instrument used to detect radiation and to measure radiation dose.

gene – A part of a living cell that controls the reproduction of the cell and determines the characteristics that the reproduced cells will have. See *chromosome.*

general license – A license issued by the Nuclear Regulatory Commission or an Agreement State for possession and use of certain radioactive materials, often for small quantities, for which no specific application is required. Individuals are automatically licensed when they buy or obtain the radioactive materials or use them in some manner. For example, luminous aircraft exit signs containing radioactive materials are licensed without any application. Airlines receive a license simply because they possess such radioactive material. Radiography companies receive a general license when they conduct radiography outside of the jurisdiction, usually a state, where they hold a specific license.

genetic defect – A defect in a living organism caused by a deficiency in the genes of the original reproductive cells from which the organism was conceived. Genetic defects are passed on to the descendants of the person with the defect.

gray (Gy) – SI unit for measurement of the dose of radiation absorbed per unit mass at a specified location. Replaces the *rad* where *rad* denotes *radiation absorbed dose,* not *radian.*
1 Gy = 1J/kg = 100 rad.

guide tube – A hollow tube through which the radiography source travels when it is cranked out of its shielded position in the camera.

Gy – Gray.

half life – The time it takes for half the atoms in a radioactive sample to decay. Half lives vary from a fraction of a second to billions of years. The half life of cobalt-60 is 5.3 years. The half life of iridium-192 is 74.2 days.

half-value thickness (or half-value layer) – The thickness of a material that will reduce the amount of radiation passing through the material to one half of its initial intensity. The thickness of the half-value thickness will depend on the material and the energy of the gamma rays.

hangup – The jamming or sticking of a radiography source outside a crank out camera.

health physicist – A trained specialist working in radiation protection.

high radiation area – An area where the radiation dose to a person could exceed 1 mSv (100 mR) in 1 hour. There are special requirements for controlling access to high radiation areas.

ICRP – International Commission on Radiological Protection. An international group of scientists representing their countries who develop recommendations on radiation dose limits and other radiation protection measures.

industrial radiography – See *radiography, industrial.*

infrared radiation – Radiant heat. Heat that is transmitted from one object to another by rays instead of by conduction between objects that touch each other. Infrared radiation is not ionizing radiation so the health effects discussed in this book do not apply to this kind of radiation.

internal contamination – Radioactive contamination within a person's body caused by radioactive material that has been inhaled or swallowed.

inverse square law – A law of nature that states how the intensity of radiation decreases as a person moves away from a radiation source of small dimension. The law states that the intensity will decrease proportionately to the distance squared. This means that moving twice as far from a source decreases the intensity of the source by a factor of two squared (2 x 2), or four.

ion – An atom that has gained or lost one or more electrons or an electron that is not attached to an atom. Ions have an electrical charge.

ion pair – A positively charged ion and an electron. The production of ion pairs is the method by which ionizing radiation gives up its energy.

ionization – The process of adding electrons to, or removing electrons from, atoms or molecules. This creates ions.

ionizing radiation – See *radiation, ionizing.*

iridium-192 – A radioactive isotope of the element iridium that emits gamma rays of energies from 0.3 MeV to 0.61 MeV. It has a half life of 74.2 days. A radioactive source used in gamma radiography. Symbols: Ir-192, ^{192}Ir, Ir^{192}.

ionization chamber (or ion chamber) – An instrument similar to a geiger counter that is used to detect and measure radiation.

isotope – A particular form of an element. The isotopes of an element have the same chemical properties but different nuclear properties. One isotope of an element may be radioactive while another isotope of the element is stable.

keV (kilo electron volts) – A unit of energy equal to 1000 electron volts.

laser beam – An intense beam of light that spreads out much more gradually than ordinary light beams.

lead screen – A thin sheet of lead placed next to the radiographic film. Gamma rays interact strongly with the lead, knocking electrons out. The electrons strike the film and cause a more intense image than if there had been no lead screen.

leak test – A check for the escape of radioactive material from a radiography source.

leukemia – An often fatal cancer characterized by excessive production of white blood cells.

licensee – The company or the person authorized to use radioactive materials under a license issued by the Nuclear Regulatory Commission or an Agreement State.

lock box – The part of a radiography camera that contains the locking mechanism used to lock the radiography source into its safe shielded position.

logarithmic decay – See *decay, logarithmic.*

logarithmic scale (or log scale) – A scale used on some graph paper where the spacings on the scale get closer and closer together as the quantity shown by the scale increases.

LSA material (low specific activity) – Radioactive material that emits very little radiation for its weight. Exactly defined in the Code of Federal Regulations.

manufactured radiation – Radiation produced by manufactured (not natural) sources, such as X-ray machines and nuclear power plants.

median lethal dose – The radiation dose that would result in the death of 50% of the people exposed to that dose. This dose is approximately 4.5 Sv (450 rem or 450 000 mrem) delivered to the whole body within a few hours or a few days.

MeV (million electron volts) – A unit of energy equal to 1 000 000 (1 million) electron volts. Used to express the energy of gamma rays and X-rays.

microwaves – A form of radiation that is non-ionizing. Microwaves are more energetic than radio waves, but less energetic than visible light. If microwaves are very intense, they can damage living cells by heating them excessively.

millirem (mrem) – A commonly used unit of radiation dose, abbreviated *mrem.* A millirem is equal to one thousandth of a rem or, in SI units, 0.01 mSv.

molecule – The smallest unit of a chemical compound. A water molecule consists of two hydrogen atoms combined with one oxygen atom; hence, the formula H_2O.

natural radioactivity – The radioactivity from naturally occurring elements that are radioactive, for example, radium, carbon-14, uranium, thorium and potassium-40.

NCRP – National Council on Radiation Protection and Measurements. A group of eminent scientists in the United States that develops recommendations on radiation protection.

negative electrical charge – An electrical charge that is attracted to positive electrical charges. Electricity is the movement of negative electrical charges (electrons).

neutron – One of the basic particles within atoms. The others are electrons and protons.

neutron radiography – See *radiography, neutron.*

non-Agreement State – A state in which the Nuclear Regulatory Commission regulates the use of radioactive materials, for example, gamma radiography. See also *Agreement State.*

nondestructive testing (NDT) – The testing or examination of an object without destroying the object to ensure that it is free from discontinuities. Industrial radiography, ultrasonic testing, magnetic particle testing and liquid penetrant testing are examples of nondestructive testing.

non-exclusive use vehicle – A vehicle used by a commercial carrier to transport packages to and from many destinations. Packages may be either radioactive or not. See *exclusive use vehicle.*

non-ionizing radiation – See *radiation, non-ionizing.*

normal form – Radioactive materials that do not have special escape proof containers. For example, liquids and powders in jars are normal form. But iridium-192 welded inside a steel capsule is not normal form, it is *special form.*

NRC – United States Nuclear Regulatory Commission. A federal agency that regulates the use of certain radioactive materials, for example, the use of iridium-192 and cobalt-60 in industrial radiography.

nucleus – The inner core of an atom or a living cell. In an atom, the nucleus consists of neutrons and protons tightly locked together. In a living cell, the nucleus contains the genes or genetic material of the cell. The plural of nucleus is nuclei.

operating procedures – A set of instructions supplied by the company on how to perform radiography exposures in that company.

OSHA – United States Occupational Safety and Health Administration. A federal agency that regulates safety in the work place, excluding radiation safety when regulated by the Nuclear Regulatory Commission or an Agreement State.

overexposure, radiation – Receiving a radiation dose in excess of legal regulatory limits. Most radiation overexposures do not have any visible medical symptoms.

overpack – An outer container for a radiography camera used to meet certain requirements for transportation, for example, to lower the radiation dose rate at the surface of the package or to add protection to an inner package.

panoramic shot or exposure – A radiographic shot or exposure in which film is exposed on a 360 degree circle around the source. For example, if the source is in the center of a pipe, a panoramic shot will radiograph the entire circumference of the pipe.

penetrating radiation – See *radiation, penetrating.*

penetrameter – A piece of metal of specific thickness with holes or slots in it. It is placed in front of the radiographic film near the area being inspected to show what size defects can be detected.

pig – A casting of metal from a mold. In radiography, pig generally refers to lead or uranium that has been cast as a shield.

pigtail – The part of a radiography source assembly that includes the short cable and connector, but not the source capsule. The term sometimes includes the source capsule as well.

pill – The sealed source capsule at the end of a radiography assembly containing the radioactive material.

placard – In transporting radioactive materials, a sign on a vehicle that indicates the vehicle is carrying packages containing radioactive materials that require Radioactive Yellow III warning labels on the packages.

pocket chamber – Another name for a *pocket dosimeter.*

pocket dosimeter – See *dosimeter, pocket.*

positive electrical charge – An electrical charge that is attracted to electrons or other negative electrical charges.

probe, radiation – A radiation detector mounted outside the case of a survey meter.

projector, gamma ray – A radiography camera.

prompt effects – The harmful health effects of radiation appearing within a day or a few weeks after exposure to a large radiation dose. The prompt effects are radiation burns and radiation sickness.

proton – One of the basic particles of an atom (the others are neutrons and electrons). Its electrical charge is the same size as that of the electron, but positive rather than negative.

quality factor – The factor by which the energy deposited by radiation (absorbed dose) is to be multiplied to obtain a quantity that expresses, on a common scale for all types of ionizing radiation, the biological damage to an exposed person. It is used because some types of radiation such as alpha particles are more biologically damaging than other types such as gamma rays and X-rays.

quartz fiber dosimeter – A pocket dosimeter. The moving part of a pocket dosimeter is a quartz fiber.

rad – A unit of radiation dose. The rad is an older unit used to tell how much energy per unit mass is deposited by radiation (absorbed dose). For gamma rays and X-rays, 1 rad is equal to 1 roentgen or 1 rem. In SI units, it is equivalent to 10 mSv.

radiation – A very broad term that refers to vibrating waves or clouds of pure energy or very fast moving atomic particles (such as electrons, beta particles, alpha particles). Radiation made of pure energy includes gamma rays, X-rays, visible light, microwaves, infrared waves, ultraviolet rays and radio waves. See also *radiation, ionizing* and *radiation, non-ionizing*.

radiation area – An area where a person could receive a radiation dose in excess of 0.5 mSv (5 mrem) in any 1 hour or 1 mSv (100 mrem) in any five consecutive days.

radiation burns – Burns in flesh caused by ionizing radiation. The burns are not caused by heat but by chemical breakdowns in the nuclei of living cells. However, radiation burns are medically similar to heat burns in effect and in treatment.

radiation dose – See *dose.*

radiation dose limits – A limit on the radiation dose that a person may receive, as established by a government regulatory agency.

radiation, electromagnetic – A technical term for radiation that travels as waves, composed purely of electrical and magnetic energy. For example, gamma rays, X-rays, microwaves, visible light, radio waves, infrared waves, and ultraviolet waves or rays.

radiation, ionizing – Any radiation that has enough energy to break apart chemical bonds and cause atoms to form ions (charged particles). For example, gamma rays, X-rays and beta particles.

radiation, non-ionizing – Radiation that does not have enough energy to create ions (charged particles). For example, visible light, radio waves and microwaves.

radiation, penetrating – Radiation that can penetrate matter deeply, such as gamma rays or neutrons. Visible light is radiation, but it is not penetrating. Microwave radiation can penetrate many materials but is not usually included as a type of penetrating radiation.

radiation safety officer (RSO) – A person who has been selected to be responsible for overseeing radiation safety in an organization. Also called by other names such as *radiation protection officer, radiation safety manager*.

radiation sickness – Sickness, possibly fatal, resulting from a large exposure to radiation in a short time, such as within several days.

radiation survey – See *survey, radiation.*

radiation, wavelike – Any radiation that travels as waves composed purely of electrical and magnetic energy. For example, X-rays, gamma rays, microwaves, visible light and radio waves. See *radiation, electromagnetic.*

radioactive – An adjective describing anything that emits radiation when unstable atoms break up.

radioactive contamination – See *contamination, radioactive.*

radioactive decay – See *decay, radioactive.*

radioactive material – A material containing unstable or radioactive atoms that break up or decay and emit radiation in the process.

radioactive waste – Waste that contains radioactive material. It must be disposed of in a safe manner according to certain regulations.

Radioactive White I Label – A warning label for packages containing radioactive material where the surface dose rate is 0.005 mSv/h (0.5 mR/h) or less. [49 CFR Section 172.436]

Radioactive Yellow II Label – A warning label for packages containing radioactive material when the surface dose rate does not exceed 0.5 mSv/h (50 mR/h) and the dose rate at 1 m (39.37 in.) does not exceed 0.01 mSv/h (1 mR/h) [49 CFR Section 172.438].

Radioactive Yellow III Label – A warning label for packages containing radioactive material where the surface dose rate is greater than 0.5 mSv/h (50 mR/h) or dose rate at 1 m (39.37 in.) greater than 0.01 mSv/h (1 mR/h) and less than 2 mSv/h (200 mR/h) on contact and 1.0 mSv/h (10 mR/h) at 1 m (39.37 in.). [49 CFR Section 172.440].

radioactivity – The emission of radiation from an unstable atom.

radiograph – A picture of an object made by the penetrating and ionizing radiation that passes through the object. Details of the inside of the object will be visible.

radiographer – A person who uses ionizing radiation, such as gamma rays or X-rays to make radiographs for the purpose of detecting discontinuities in objects without destroying them.

radiographer's assistant – An individual who helps a radiographer and who has received some training and is being trained to become a radiographer.

radiographic exposure device – The term used in Nuclear Regulatory Commission regulations to mean a radiography camera. (See *camera, radiography.*)

radiography – The use of penetrating radiation to make pictures of the inside of objects. If the pictures are of industrial goods, it is called *industrial radiography*. If the pictures are of medical patients, it is called *medical radiography, medical radiology,* or *radiology*.

radiography camera – See *camera, radiography*.

radiography cell – See *cell, radiography*.

radiography, gamma – Industrial radiography using radioactive materials that emit gamma rays.

radiography, industrial – The use of penetrating radiation, such as X-rays, gamma rays or neutrons, to make pictures of the insides of objects, for example, to inspect metal castings or welds for internal discontinuities. Industrial radiography does not include medical uses of radiation.

radiography, neutron – Industrial radiography using neutrons as the penetrating radiation.

radiography source – See *source, radiography*.

radiography, X-ray – Industrial radiography using X-ray machines as the source of radiation.

radioisotope (or radioactive isotope) – A form (isotope) of an element that is radioactive. For example, cobalt-60 is a radioisotope.

radium (or radium-226) – A naturally occurring radioactive material used in the first gamma radiography sources, but not used any more.

range switch – A switch on a radiation survey meter that changes the scale of the meter, for example, from "0 to 10 mR/hour" to "100 to 1000 mR/hour".

rate, dose – A measure of the speed at which dose accumulates, for example, 10 μSv (1 mrem) per hour. Similar to the speed of an automobile in miles per hour, which is a mileage rate.

reciprocity – The recognition by the Nuclear Regulatory Commission or by an Agreement State of a license issued by the other. Reciprocity allows a radiography company licensed in one jurisdiction (usually a state) to work in a different jurisdiction where it is not specifically licensed.

rem – An older unit of radiation dose. A rem is equal to 1000 mrem. It has been replaced by the SI unit *sievert*.

restricted area – An area to which access is controlled for the purpose of radiation protection. If the dose to a person from radioactive material could exceed 20 μSv (2 mrem) in any 1 hour or 1 mSv (100 mrem) in any 1 week, access to the area must be restricted.

roentgen – A unit of radiation dose. Abbreviated *R*. A roentgen is equal to 1000 mR (mA) or 10 mSv in SI.

Roentgen, Wilhelm – The German scientist who discovered X-rays in 1895.

rotor shaft – A shaft or axle in a beam type camera that is rotated to expose the source.

RSO, radiation safety officer – See *radiation safety officer*.

S-tube – A curved tube inside the shield of a crank out radiography camera. The radioactive source enters and exits the camera through the S-tube. The S-tube is shaped like the letter *S* so that a beam of radiation cannot escape through the tube when the source is in its shield.

safety plug – A plug put in the S-tube entrance of a crank out camera to keep dirt out and prevent the source from moving out if the lock is not working.

scintillation counter – An instrument that detects radiation by counting the small flashes of light (scintillations) the radiation produces when it hits certain crystals.

sealed source – Radioactive material sealed in a capsule designed to prevent leakage or escape of the material.

semilogarithmic graph paper (or semilog paper) – Graph paper with one logarithmic scale and one normal scale.

shield – A structure made of shielding material to reduce radiation levels.

shield, shadow – A shield that partially shields radiation from a source. The shield creates a shadow where there is little radiation.

shielding (or shielding material) – Material that can be placed around a radiation source for the purpose of reducing radiation levels.

shim – A piece of metal placed under a penetrameter to make the metal section under the penetrameter as thick as the section of weld being radiographed.

shot – Exposing a radiography source to make a radiograph. Also called an *exposure*.

SI – International Standard of units of measurement. An international system of measurement based on seven units: meter (m), kilogram (kg), second (s), kelvin (K), ampere (A), candela (cd) and mole (mol). The units used to measure radiation are *becquerel* (Bq), *coulomb* (C), *gray* (gy) and *sievert* (Sv).

sievert – SI unit for measurement of exposure to ionizing radiation, replacing rem. 1 Sv = 1 J/kg = 100 rem

source – This term can refer either to any source of radiation or to a radiography source in particular.

source assembly – The radiography source, including the source capsule, the pigtail cable and the connector for connecting it to the drive cable.

source capsule – The steel capsule that the radioactive materials are welded within to make the radiography source.

source changer – A shielded container with two holes for sources. The old source is cranked into the changer and the new source is cranked out.

source conduit – A source guide tube.

source port protector cap – A safety plug or cap that fits over the S-tube through which the source exits (in a crank out camera).

source, radiation – Any source of radiation.

source, radioactive – Any source of radiation where the radiation is produced by the decay of radioactive materials rather than electrically as in X-ray machines.

source, radiography – The radiation source containing radioactive material used in gamma radiography. Radiography source may refer to the entire source assembly, to the source capsule or to the gamma radiation being emitted for making radiographs.

special form – Radioactive material in a form that limits leakage or dispersal of the material. Radiography sources are special form materials because the radioactive material is contained in a steel capsule that is welded closed.

specific activity – The activity per unit weight of material, for example, becquerel (curies) per gram. Uranium has a very low specific activity because there are very few disintegrations for a given weight. Iridium pellets in a radiography source have a much higher specific activity.

specific license – A license issued to a company or person to possess and use radioactive material after specific written application has been made. See *general license.*

survey meter, radiation – A portable instrument that measures radiation dose rate (radiation intensity).

survey, radiation – As used in this book, a radiation survey is a measurement of the levels of radiation taken by using a radiation survey meter. In Nuclear Regulatory Commission regulations, a survey may also include an evaluation of the radiation hazard (for example, by calculation) and may not necessarily include measurements using a survey meter.

syndrome, acute radiation – The medical term for *radiation sickness.*

tenth-value thickness (tenth-value layer) – The thickness of a material that will reduce the amount of radiation passing through the material to one tenth of its original intensity. The tenth-value thickness will depend on the material and the energy of the gamma rays.

thermoluminescent dosimeter – See *dosimeter, thermoluminescent.*

thorium – A naturally occurring radioactive material like uranium.

thulium-170 – A radioactive form of the element thulium that emits gamma rays with an energy of 91 KeV. It has a half life of about 129 days. A source used in industrial radiography. Symbols: Tm-170, ^{170}Tm, Tm^{170}.

TLD – Thermoluminescent dosimeter. See *dosimeter, thermoluminescent.*

transport index (TI) – Established by the Department of Transportation, the transport index is the highest dose rate in mR/h at 1 m (39.37 in.) from the package. If the highest dose rate at 1 m (39.37 in.) is 5 mR/h, the transport index is 5.

tritium – A radioactive form (isotope) of the element hydrogen.

Type A or Type B packaging – A special type of packaging that meets specific regulations for transporting radioactive materials. Most radiography sources require Type B packaging. Exact requirements are given in the Code of Federal Regulations.

ultraviolet light or **ultraviolet radiation** – A form of radiation that is similar to visible light but is a little more energetic. It is much less energetic than X-rays or gamma rays and does not ionize molecules. Therefore, it is non-ionizing radiation.

United States Nuclear Regulatory Commission – See *NRC.*

unrestricted area – An area in which the radiation dose to a person would be less than 20 μSv (2 mrem) in any 1 hour or 1 mSv (100 mrem) in 1 week.

UNSCEAR – United Nations Scientific Committee on Effects of Atomic Radiation. A committee of internationally known scientists that reports to the United Nations on the effects of radiation.

uranium – A naturally occurring radioactive material used as a shielding material in radiography cameras. It is also used to fuel nuclear power plants. See also *depleted uranium.*

utilization log – A written record to keep track of the use of a radiography source.

warning labels – In radiography, the labels attached to a shipment of radioactive material indicating the radioactive contents and dose rates. See *Radioactive White I, Radioactive Yellow II,* and *Radioactive Yellow III Labels.*

wavelike radiation – See *radiation, wavelike.*

White I Label, Radioactive – See *Radioactive White I Label.*

wipe test – Same as a *leak test.* See definition.

Yellow II Label, Radioactive – See *Radioactive Yellow II Label.*

Yellow III Label, Radioactive – See *Radioactive Yellow III Label.*

X-ray – Radiation similar to light, but more energetic and therefore more penetrating. X–rays can cause damage to living things. They are usually produced by bombarding a metallic target with electrons.

ytterbium-169 – A radioactive form of the element ytterbium that emits gamma rays of energy 19 and 76 KeV. It has a half life of 32 days and is occasionally used in industrial radiography. Symbols: Yb-169, ^{169}Yb, Yb^{169}.

Appendix D
Overexposure Accidents 1971-1980

Table 1: People overexposed to external radiation reported by Nuclear Regulatory Commission licensees, 1971-1980. (Though the information in this table is out of date, it is included in this book for its historic importance.)

Total overexposures
12.5 mSv or 30 mSv (1.25 rem or 3 rem) whole body or 187.5 mSv (18.75 rem) extremity

Year	All Licensees	Gamma Radiography
*1971	57	24
1972	59	21
1973	65	24
1974	103	29
1975	39	13
1976	52	20
1977	62	10
1978	27	6
**1979	56	11
***1980	92	4
Total	612	162 (26%)

Overexposures greater than 50 mSV (5 rem) whole body or 750 mSv (75 rem) extremity

Year	All Licensees	Gamma Radiography
*1971	11	9
1972	12	6
1973	12	7
1974	13	5
1975	2	2
1976	14	14
1977	4	3
1978	7	2
**1979	8	3
***1980	1	1
Total	87	52 (60%)

Overexposures greater than 250 mSV (25 rem) whole body or 3.75 Sv (375 rem) extremity

Year	All Licensees	Gamma Radiography
*1971	3	3
1972	3	3
1973	2	2
1974	2	1
1975	1	1
1976	4	4
1977	2	1
1978	1	0
**1979	0	0
***1980	3	0
Total	21	15 (71%)

* The values in this table for the years 1971-1978 are from published NRC Occupational Radiation Exposure Annual Reports, such as NUREG-0493 for the year 1978.
**1979 data provided by Barbara Brooks of NRC's Office of Management and Program Analysis, May 1981.
***1980 data were supplied by Gene Trager of NRC's Office for Analysis and Evaluation of Operational Data, November 1981. They were considered preliminary data at the time of the original printing of this information.

Table 2: Gamma radiography overexposure accidents, 1971-1980.
A list of all radiation overexposures reported by Nuclear Regulatory Commission licensed radiography companies exceeding 50 mSv (5 rem) to the whole body or 0.75 Sv (75 rem) to a part of the body*.
(Though the information in this Table is out of date, it is included in this book for its historic importance.)

No.	Date	Company	Source	Dose	Symptoms	Why Was Source Exposed?	Was a Survey Made?	Other Factors
1.	1/4/71	Black Sivalls and Bryson	9 Ci Co-60	8 rems WB	None	Radiographer apparently forgot to retract source.	No	
2.	1/12/71	Conam Inspection	27 Ci Ir-192	13 rems WB	None	Source stuck at camera entrance because of dirt and grit in crank mechanism.	Yes, but only from rear of camera. Survey did not detect source.	Occurred at change of shift.
3.	1/27/71	Jones Testing	26 Ci Ir-192	6 rems WB	None	Two sources were in use in a permanent inplant facility. Radiographer cranked out the second source instead of cranking in the first source.	Apparently not	Radiographer had no training.
4.	1971 & previous year	Newport News Shipyard	0.01 Ci Co-60 (fishpole type)	2000 to 3000 rems to hand	Uncertain, but chronic radiation dermatitis is possible from these doses	Radiography supervisor handed out source in his hands over a 29-month period.	Not applicable	
5.	7/9/71	Newport News Shipyard	220 Ci Ir-192	7 rems WB	None	A rough or kinked guide tube caused the source to jam.	No, because meter was not operating.	The radiographer disconnected the gamma alarm after the source jammed because he thought the alarm was malfunctioning.
6.	9/8/71	Pittsburgh Testing	96 Ci Ir-192	600 rems or less based on lack of symptoms	None	Not fully retracted for unknown reason.	Yes, but did not carry meter to camera.	The radiographer disconnected the guide tube before locking the camera. He instinctively reached out and touched the source when he saw it. He thought it was the safety plug.
7.	9/30/71	Peabody X-Ray Engineering	73 Ci Ir-192	5 rems WB	None	Source disconnected when it got hung up at device entrance. A worn or wrong size connector was used.	No	
8.	10/20/71	Inspection Signal Services	80 Ci Ir-192	540 rems to hand	None	Upon starting work the radiographer opened the front plug and found the source there. An incompatible control cable may have been used.	No	
9.	11/71	Conam Inspection	68 Ci Ir-192	6 rems WB	None	Source jammed.	Yes	The jammed source was discovered, but the radiographer was overexposed during the recovery operation.
10.	3/24/72	Peabody/ Magnaflux	70 Ci Ir-192	21 rems WB	None	Source disconnected and stayed at end of guide tube because it had not been connected properly (GI connector).	No	The radiographer was using locking as a subtitute for a survey. In this case the camera locked without the source being in.
11.	7/72	Froehling and Robertson	108 Ci Ir-192	400 to 1000 rems to hand	Reddening of hand.	Source jammed at entrance to camera, then became disconnected.	No. No survey meter was available at the site.	The radiographer called the company to report the source disconnect. They told him to shake it loose, pick it up by hand, and put it back in the camera. The radiographer thought the procedure would be dangerous and refused. By phone the company told an untrained person to do the job. He did and was overexposed.
12.	9/8/72	Magnaflux Testing Laboratory, Pittsburgh	83 Ci Ir-192	10,000 rems to hands 22 rems WB	Severe burn, loss of fingers	Forgot to retract source.	No	

13.	10/17/72	Conam Inspection	80 Ci Ir-192	8 rems WB	None	The radiographer rolled up the control cables before locking the camera. This caused the source to creep out.	Yes	
14.	12/22/72	X-Ray Engineering	38 Ci Ir-192	22,000 to 30,000 rems to fingers	Severe burn, amputation of fingers	The radiographer confused "in" and "out." He cranked the source "out" when he wanted it "in."	No	The job was at night. The radiographer was tired and was hurrying to finish the job.
15.	1973	Duriron Co.	42 Ci Ir-192	28 rems WB	None	A radiographer's assistant entered the inplant exposure room while the source was exposed. He ignored a functioning gamma alarm.	No	
16.	2/19/73	Inspection Service of Pennsylvania		5 rems WB	None	Source jammed in a crimped guide tube. Guide tube was crimped because camera had fallen earlier in the day. Pulling caused the source to disconnect.	Yes	Emergency procedures were followed, but overexposure still resulted.
17.	6/8/73	General Dynamics Electric Boat	101 Ci Ir-192	10 rems WB plus 550 rems to hip	None	Source was not quite fully retracted. A blinking warning light was ignored.	No. Survey meter was broken by a very severe blow during the work. The radiographer said he did not damage the survey meter.	There may have been a communication failure between the radiographer and his assistant, but it is also possible that she was intentionally exposed by someone.
18.	8/30/73	Universal Technical Testing Laboratories, Inc. (PA)	36 Ci Ir-192	7 rems WB & 5 rems WB	None	Source crept out of the camera when it was moved without the source being locked in.	Yes	
19.	9/15/73	American Ship-building Co.	60 Ci Ir-192	87 rems to hand	None	An untrained person attempted to connect the source to the control cable, but did not make a connection (Al connector).	Yes	The untrained person realized the source was out, but still disconnected the guide tube.
20.	11/7/73	Consolidated X-Ray Service Co.	45 Ci Ir-192	5 rems WB	None	Camera fell over into mud pinching the guide tube, and making retraction impossible until the guide tube was straightened. The radiographer was overexposed as he straightened the guide tube.	Yes	Difficult environmental conditions contributed to the accident.
21.	12/18/73	Pittsburgh Testing Lab		7 rems WB	None	Radiographer apparently forgot to retract source.	No	
22.	1974	Midstate Inspection Engineering	25 Ci Ir-192	9 rems WB	None	An inexperienced radiographer's assistant did not fully crank in the source.	No	Poor training was a factor.
23.	1974	Dravo Corp., Ohio		175 rems to hand and 6 rems WB	None	A radiographer forgot to retract the source at the end of his work shift. The radiographer on the next shift was exposed.	No, not by the radiographer quitting work or the radiographer on the next shift.	Hurrying to quit work was a factor.
24.	4/29/74	Conam Inspection	13 Ci Co-60	7 rems WB	None	Source jammed in the guide tube near the camera because the radiographer bent it too sharply.	No	The radiographer did not understand the limitations of the guide tube.
25.	6/4/74	U. S. Testing	20 Ci Ir-192	5 rems WB	None	Unknown	Yes, but the radiographer did not understand the meter readings.	Radiographer was not properly trained in use of survey meter.
26.	10/25/74	X-Ray Industries	52 Ci Ir-192	11 rems WB and 300 rems to eye	None	Two radiographers were working together. The radiographer who was exposed thought the other radiographer had retracted the source, but he had not.	No	Poor communication was a factor. A timing buzzer rang. One radiographer shut the buzzer off but did not crank in the source. The other radiographer assumed that since the buzzer had been shut off the source had also been cranked in. But neither radiographer had cranked the source in.
27.	3/30/75	Texas Pipe Bending Co. of Puerto Rico	Ir-192	6 rems WB	None	Unknown	Unknown	

No.	Date	Company	Source	Dose	Symptoms	Why Was Source Exposed?	Was a Survey Made?	Other Factors
28.	11/11/75	Value Engineering Co.		28 rems WB	None	It is possible that the radiographer forgot to retract the source, but it is also possible that he intentionally exposed his badge.	Unknown	
29.	1/8/76	X-Ray Engineering		7 rems WB	None	Unknown	Unknown	
30.	2/7/76	Exam Co.	97 Ci Ir-192	5 rems WB	None	The source was not quite fully retracted for unknown reasons.	Yes, but only the back of the camera was surveyed.	The radiographer's assistant who surveyed did not know how to survey properly.
31.	4/27/76	Exam Co.	93 Ci Ir-192	6 rems WB	None	Unknown.	No. Assistant did not survey.	
32.	7/8/76	NES/Conam Inspection	44 Ci Co-60 and 92 Ci Ir-192	24 rems WB, 7 rems WB, 7 rems WB	None None None	A radiographer forgot to retract the cobalt-60 source. Upon discovering his error he cranked out the iridium-192 source thinking he was cranking in the cobalt-60 source.	Surveys were erratic, not made, or not understood.	Two sets of cranks caused confusion.
33.	7/13/76	Universal Technical Testing Laboratories, Inc. (PA)	71 Ci Co-60	6 rems WB	None	The radiographer forgot to retract the source while hurrying to finish before lunch.	Not really. The radiographer carried the meter but did not read it.	Hurrying was a factor. A gamma alarm was ringing but the radiographer shut it off.
34.	8/4/76	Globe X-Ray Services	70 Ci Ir-192	23 rems WB	None	Unknown		Unknown
35.	10/9/76	Yuba Industries	103 Ci Ir-192	6 rems WB	None	The camera was moved without being locked. Apparently the motion caused the source to creep out.	Yes	
36.	11/3/76	Arnold Green Testing Lab	30 Ci Ir-192	10 rems WB	None	Radiographer was not careful to fully retract source.	No	While working the radiographer became very ill. This led to incomplete retraction of the source and omission of the survey.
37.	11/4/76	NES/Conam Inspection, Rosemont, Illinois.	47 Ci Co-60	The actual doses to the two hands of two radiographers were probably less than 600 rems since no physical symptoms were present.	Apparently none.	A bend in the guide tube caused the source to jam near the camera.	Yes, but the back of the camera was surveyed and the exposed source was not detected.	Poor training in how to make a survey was a factor.
38.	11/12/76	Pittsburgh Des Moines Steel Company	94 Ci Ir-192	About 1000 rems to fingers of right hand based on physical symptoms and 5 rem WB.	A dry blister formed and fell off. No infection. Wound healed.	Source was not fully retracted (left 1 ft outside camera). No reason was identified.	No	
39.	12/12/76	Atlantic Research	166 Ci Co-60	1100 to 1400 rems to hand	Reddening of the skin on fingers, but no fingers were lost.	Forgot to retract source.	No. In addition, a gamma alarm in the exposure room had been disconnected so that the door could be propped open to obtain ventilation.	The radiographer had come in on Sunday morning at the company's request. His wife was in the hospital having a baby, but he did not tell the company managers. There was poor communication between the radiographer and the managers.
40.	6/16/77	J. G. Sylvester Associates, Inc.	35 Ci Co-60 and 94 Ci Ir-192	400 rems to head	None	At the end of an Ir-192 exposure, the Co-60 source was cranked out by mistake instead of cranking in the Ir-192 source.	Not really. A survey meter was carried but not looked at.	

41.	9/7/77	General Dynamics Electric Boat	80 Ci Ir-192	5 rems WB	None	Source was not fully retracted.	No. The radiographer was relying on a "chirper," but the background noise was so loud he could not hear it.	
42.	11/12/77	Pittsburgh Des Moines Steel	75 Ci Ir-192	300-600 rems to fingers	None	Source did not retract to the fully shielded position.	Yes, but the survey did not include the front of the camera.	Poor survey technique.
43.	6/3/78	Union Boiler Company	85 Ci Ir-192	120 rems to thumb	None	The radiographer retracted the source and tried to lock the camera, but the camera would not lock. He retracted the source again and tried locking, again without success. He concluded that fly ash had jammed the locking mechanism.	Yes. The meter needle read off scale, but an audible speaker was silent. The radiographer concluded that moisture and fly ash had shorted the meter causing the needle to go off scale.	
44.	11/15/78	Twin City Testing Engineering Lab	Ir-192	22 rems to trunk (lower back of body)	None	The source was not fully retracted for unknown reasons.	Yes, but the survey was not complete enough to show that the source was not fully retracted.	
45.	3/7/79	Townsend and Bottum, Inc.	65 Ci Ir-192	9 rems to left calf	None	The source was retracted but not fully, perhaps because of a tight bend in the guide tube. One more turn of the crank was needed.	Yes, but not carefully.	Work being done late at night. Heavy work load. Radiographer distracted and worried by phone call from supervisor.
46.	10/10/79	Consolidated X-Ray Service Co.	Ir-192	9 rems WB	None	The source was retracted and the locking mechanism did not catch the locking ball. This allowed the source to move out of the fully shielded position when the control cable was coiled.	Yes, but the source crept out after the survey had been made.	
47.	12/13/79	Tulsa Gamma Ray, Inc.	80 Ci Ir-192	17 rems on film badge	Probably none, but individual could not be located afterwards.	Intentional exposure.	Not applicable.	The individual had been fired the day before the exposure for being drunk on the job after working for the licensee for 7 days. He returned drunk the next morning, cranked out the source, and handed his film badge to the supervisor. It is not known whether he was exposed or whether just the film badge was exposed.
48.	6/12/80	Consumers Power	55 Ci Ir-192	8 rems WB	None	The crank assembly apparently jammed so that the source was not fully retracted, unknown to the radiographer.	Yes, but the assistant radiographer did not survey the front of the camera.	

*Source: Compiled by the original author, Steven A. McGuire, from letters and reports contained in the files of the Nuclear Regulatory Commission's Office of Inspection and Enforcement.

NOTE: No overexposures greater than 50 mSv (5 rem) to the whole body (WB) or 0.75 Sv (75 rem) to the extremities were reported to the NRC by its radiography licensees for the period January 1, 1981 through August 31, 1981. However, two people involved in manufacturing radiography sources suffered serious damage to their hands during this period.

Appendix E
References and Notes

Chapter 1

1. Charles W. Briggs, "Developments in Gamma Ray Radiography, 1928-1941," *Industrial Radiography*, Vol. 1, Summer 1942, p. 7. (Reprinted in *Materials Evaluation*, Vol. 39, pp. 356-359, March 1981.)

2. Clyde B. Clayson, "Gamma Ray Testing of Welds," *Industrial Radiography*, January 1943, p. 17.

3. *Nondestructive Testing Handbook*, third edition: Volume 4, *Radiographic Testing*, Columbus, OH: American Society for Nondestructive, 2002.

This nondestructive testing text heavily references other documents. See this volume for further bibliographic information.

Chapter 2

1. National Council on Radiation Protection and Measurements, *Natural Background Radiation in the United States*, NCRP Report No. 45, Washington, D.C., 1975.

This is considered the most authoritative source of information on natural background radiation in the United States. The doses given in Chapter 2 are appropriate for most body organs, including bone marrow, gastrointestinal tract, and gonads. Doses to the bone surface are 1.2 mSv/year (120 mrem/year) and to the lung are 1.8 mSv/year (180 mrem/year).

2. National Council on Radiation Protection and Measurements, *Radiation Exposure From Consumer Products and Miscellaneous Sources*, NCRP Report No. 56, Washington, D.C., 1977. This reference gives the dose from natural radioactivity in building materials. This dose could be classified as either natural or manufactured. It seemed more appropriate to consider it to be natural background radiation to us.

3. Merril Eisenbud, *Environmental Radioactivity*, Academic Press, New York, 1973, pp. 199-204.

4. B. Schleien, T.T. Tudser, and D.W. Johnson, "The Mean Active Bone Marrow Dose to the Adult Population of the United States from Diagnostic Radiology," *Health Physics*, Vol. 34, p. 587, June 1978.

We believe this is the most authoritative study of radiation exposure in the United States from medical and dental diagnostic X-rays. The study estimates a dose of 0.77 mSv (77 mrem) per year to active bone marrow to the United States population in 1970. Active bone marrow is used because this is considered to be the dose most relevant to cancer induction. The dose received is averaged over the active bone marrow in the entire body. Thus, dental X-rays, which give a high dose to a small part of the body, contribute only 30 μSv (3 mrem) per year when averaged over the entire body's active bone marrow.

If only adults are considered, the United States average dose from diagnostic X-rays is 1.03 mSv (103 mrem) per year because adults receive more X-rays than children. The dose to the gonads is often calculated because it is the genetically significant dose. The gonad dose from diagnostic X-rays is 0.20 mSv/year (20 mrem/year) according to the Bureau of Radiological Health. This is lower than the active bone marrow dose because the gonads are not often in the direct X-ray beam and because the genetically significant gonadal dose is reduced to account for the proportion of a person's reproduction that has passed. Older people, who receive most X-rays, will have few additional children, so their genetically significant gonadal dose is small.

Thus, in comparing these estimates with other estimates, it is necessary to consider (1) does the estimate apply to the whole body or to some specific organ such as the lungs? (2) does the estimate apply to the total population or to adults only? and (3) is the dose estimate weighted for cancer significance or genetic significance?

5. United States Environmental Protection Agency, *Radiological Quality of the Environment*, EPA Report EPA-520/1-77-009, Washington, D.C.,1977.

To determine total medical dose, the dose from radioactive materials injected into the body for diagnostic purposes must be added to the dose from diagnostic X-rays. The United States Environmental Protection Agency has estimated that this source of radiation adds roughly 20% to the medical X-ray dose. The value for fallout from nuclear weapons tests is also from the above EPA report.

6. Interagency Task Force on the Health Effects of Ionizing Radiation, *Report of the Work Group on Exposure Reduction*, United States Department of Health, Education, and Welfare, 1979.

The value of 3 μSv (0.3 mrem) per person per year from nuclear power is taken from this reference. About two thirds of the dose comes from radioactive radon-222 gas that escapes from piles of uranium ore either before or after the uranium has been extracted. About 80% of the remainder comes from reprocessing of spent nuclear fuel. The operation of nuclear power plants contributes very little to the dose.

7. National Council on Radiation Protection and Measurements,

Radiation Exposure from Consumer Products and Miscellaneous Sources, NCRP Report No. 56, Washington, D.C. 1977.

The value of 10 mSv/year (1 mrem/year) for consumer products, exclusive of building materials (which we listed as natural background radiation), is from this reference.

8. B. Brooks, S. McDonald, and E. Richardson, *Occupational Radiation Exposure – Eleventh Annual Report – 1978*, NRC Report NUREG-0593, 1981.

The average dose of 13 mSv (1.3 rem) for radiographers is on page 60.

9. The standard practice with personnel dosimeters is to subtract natural background radiation by subtracting the reading on a control dosimeter. This subtracts radiation dose from natural background sources, from radiation received while in transit, and from thermal fogging of film. This procedure is followed by R.S. Landauer (per Robert Wheeler), Eberline (per Eric Geiger) and Seamans (per Robert Pollock).

10. Reports to the NRC of radiographers using personnel monitoring tend to exaggerate the number of people working as radiographers and tend to greatly underestimate the dose received by an actively working radiographer. For example, in 1978 an NRC radiography licensee (Bethlehem Steel, Steelton, Pennsylvania) reported 27 people monitored of whom 25 had no measurable exposure. The other two had exposures under 1 mSv (100 mrem). Anthony Lamastra of Bethlehem Steel said that of the 27 monitored only about five or six were authorized to work with the licensee's one radioactive source. The others were monitored because they worked in a department with a cabinet X-ray machine. The licensee estimated that in 1978 only about 10 shots had been made and that less than 10 staff hours of work was spent using the radioactive gamma source during the year. Situations like this greatly lower the average dose received by radiographers.

The average annual dose reported by the NRC for radiographers is well below the dose that can be expected by a field radiographer working regularly for a year.

11. Reports from NRC licensees (such as in Reference 8) show that almost 1000 radiographers receive doses exceeding 10 mSv (1 rem) each year. The NRC had about 360 gamma radiography licenses outstanding in 1978. Agreement States issued about 681 (as of December 1979, NRC Office of State Programs unPublished report, "Licensing Statistics and Other Data").

States where extensive field radiography is performed tend to be Agreement States. This is because the major oil producing states are Agreement States and field radiography is performed extensively in connection with the oil industry. NRC licensees are more likely to do in plant radiography in factories in the Midwest and Northeast. Higher doses are associated with field radiography because shielding walls are not available. From these facts, we estimate that roughly 3000 to 4000 radiographers received doses exceeding 10 mSv (1 rem) per year.

12. Centaur Associates, Inc., "An Economic Study of the Radionuclides Industry," unpublished report submitted to the NRC, February 15, 1980.

This report estimated 4500 gamma radiographers directly involved in making radiographs in the United States (both NRC and Agreement State licensed) in 1978, based on a survey of licensed companies. (A summary of this information is on page 60 of Reference 8.) Our own feeling is that the estimated number of 4500 radiographers is an underestimate and does not include people who occasionally work as radiographers. We have rather arbitrarily increased their estimate to 10 000 people to account for these. The value seems a reasonable compromise between the 4500 in Reference 11 and the 13 000 monitored by NRC licensees plus an estimated 26 000 monitored by state licensees of which 6700 had measurable radiation doses (Reference 8). Independently, John Munro of Tech/Ops, Inc., also concluded that there were about 10 000 radiographers in the United States.

13. United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), *Sources and Effects of Ionizing Radiation*, United Nations, New York, 1977, p. 263. (This is often called the "1977 UNSCEAR Report".)

Based on NRC reports of doses received by workers who terminated employment, these estimates were obtained:

Length of Employment (years)	5-10	10-15	15-20
Estimated Lifetime Dose in sievert (rem)	0.19 (19)	0.14 (14)	0.14 (14)

These numbers were rounded off to 20 rem lifetime dose in the original publication of this book.

14. *Nondestructive Testing Handbook*, third edition: Volume 4, *Radiographic Testing*, Columbus, OH: American Society for Nondestructive, 2002.

This nondestructive testing text heavily references other documents. See this volume for further bibliographic information.

Chapter 3

1. C. Michael Lederer and Virginia S. Shirley, Eds., *Table of Isotopes*, Seventh Edition, John Wiley and Sons, Inc., New York, p. 1231, 1978.

There are about 2.23 gamma rays per disintegration of iridium-192, according to this reference.

2. From January 1979 through July 1981, NRC licensees reported three leaking sources to NRC, according to Samuel Pettijohn, NRC, Office for Analysis and Evaluation of Operational Data, and Earl Wright, NRC, Office of Nuclear Material Safety and Safeguards.

3. NRC Office of Inspection and Enforcement, "Preliminary Notification of Event or Unusual Occurrence," PNO-I-80-106, July 22, 1980, and information supplied by John E. Glenn, NRC, Region I Office, 1981.

Chapter 4

1. Percy Brown, *American Martyrs to Science through the Roentgen Rays*, Charles C. Thomas, Springfield, Illinois, 1936.

2. Daniel S. Grosch and Larry E. Hopwood, *Biological Effects of Radiation*, Second Edition, Academic Press, New York, pp. 3 and 4, 1979.

But contrary to the description in the book, Becquerel was burned by radium, not uranium, according to Frederick G. Spear, *Radiation and Living Cells*, Chapman and Hall, 1953.

3. Eugene L. Saenger, James G. Kereiakes, Neil Wald, and George E. Thomas, "Clinical Course and Dosimetry of Acute Hand Injuries to Industrial Radiographers from Multicurie Sealed Gamma Sources," *The Medical Basis for Radiation Accident Preparedness* (Karl F. Hubner and Shirley A. Fry, editors), Elsevier/North-Holland, New York, pp. 169-178, 1980.

The description of the symptoms of radiation burns was taken from this reference. Information on chronic radiodermatitis is from: Wright H. Langham, editor, *Radiological Factors in Manned Space Flight*, National Academy of Sciences National Research Council, pp. 147-157, 1967.

4. Joseph F. Ross, Francis E. Holly, Harvey A. Zarem, Cappy M. Rothman, and Alan L. Shabo, "The 1979 Los Angeles Accident: Exposure to Iridium-192 Industrial Radiographic Source," *The Medical Basis for Radiation Accident Preparedness* (Karl F. Hubner and Shirley A. Fry, eds.), Elsevier/North-Holland, New York, pp. 205-221, 1980.

5. F. Eugene Holly and William L. Beck, "Dosimetry Studies for an Industrial Radiography Accident," *The Medical Basis for Radiation Accident Preparedness* (Karl E. Hubner and Shirley A. Fry, editors) Elsevier/North-Holland, New York, pp. 265-277, 1980.

6. This incident is the same as discussed in NUREG/BR-0001,Volume 1, Case History 4. That report was based on preliminary information. The later studies above estimated the source strength to be 1.04 TBq (28 Ci) rather than 1.48 TBq (40 Ci), and the time in the worker's back pocket to be 45 min (rather than 2 hours). The dose to the surface of the skin cannot be precisely determined because the dose depends very strongly on the precise distance between the source and the worker's skin.

Based on Figure 3 in Reference 5 and an assumed 1 cm distance, the skin surface dose would be very roughly 200 Sv (20 000 rem) rather than 15 000 Sv (1.5 million rem). Dose estimates of up to 10 000 Sv (1 million rem) can be calculated for a single point on the surface of the skin if one assumes the source was touching the skin. However, we considered 200 Sv (20 000 rem) a more reasonable estimate for estimating actual damage to a piece of skin of significant size. Radiation doses above 30 Sv (3000 rem) cause complete destruction of tissue.

7. M. Annamalai, P.S. Iyer, and T.M.R. Panicker, "Radiation Injury from Acute Exposure to an Iridium-192 Source: Case History," *Health Physics*, Vol. 35 (Aug.), pp. 387-389, 1978.

8. D. Beninson, A. Placer, and E. Vander, "Estudio de un caso de irradiacion humana accidental," *Proceedings of the Symposium on the Handling of Radiation Accidents*, IAEA, Vienna, pp. 41 5-429, 1969.

9. K.Z. Morgan and J.E. Turner, *Principles of Radiation Protection*, John Wiley and Sons, Inc., New York, Chapters 12 and 13, 1967.

10. International Commission on Radiological Protection, *The Principles and General Procedures for Handling Emergency and Accidental Exposures of Workers*, ICRP Publication 28, Pergamon Press, Oxford, p. 16, 1977.

11. Ye Gen-yao, Liu Yong, Tien Nue, Chaing Ben-yun, Chien Fengwei, and Yiae Chien-ling, "The People's Republic of China Accident in 1963," *The Medical Basis for Radiation Accident Preparedness* (Karl F. Hubner and Shirley A. Fry, editors), Elsevier/North-Holland, New York, pp. 82-89, 1980.

12. R.J.P. Le Go, M.T. Deloy, J.L. Malarbet, M. Veyrat, "Clinical and Biological Observations of Seven Accidentally Irradiated Algerian," Report of the French Comissariat a l'Energie Atomique, CEA-CONF-4659, 1979.

13. Reference 9, p. 54.

14. Information on how the source was left with the watchman was obtained from Dr. Julián Sénchez-Gutiérrez, Director, Safety of Nuclear Facilities, Commission Nacional de Seguridad Nuclear y Salvaguardias, Mexico City, Mexico.

15. *Vital Statistics of the United States - 1977*, Volume II-Mortality, United States Department of Health and Human Services, Public Health Service, Table 7-5, 1980.

The respiratory diseases include influenza, pneumonia, bronchitis, emphysema and asthma.

16. The following three reports written by committees of eminent scientists are basically in agreement on the upper limit of risk of cancer death: "The BEIR III Report": *The Effects on Populations of Exposure to Low Levels of Ionizing Radiation*, Report of the Committee on the Biological Effects of Ionizing Radiation, National Academy of Sciences, Washington, 1980.

"The UNSCEAR Report": *Sources and Effects of Ionizing Radiation*, United Nations Scientific Committee on the Effects of Atomic Radiation, UN Publication E.77.IX.I, New York, 1977.

"ICRP 26": *Radiation Protection, Recommendations of the International Commission on Radiological Protection*, ICRP Publication 26, Pergamon Press, Oxford, 1977.

17. *Accident Facts*, National Safety Council, 1979.

Career lifetime accidental deaths are calculated by using annual death rates multiplied by an assumed working lifetime of 40 years.

18. R.L. Gotchy, "Estimation of Life Shortening from Radiogenic Cancer per Rem of Absorbed Dose," *Health Physics*, Vol. 35, pp. 563-565, October 1978.

Dr. Gotchy states, "One would expect the life shortening of occupationally exposed workers in the nuclear industry to lie between 0.63 and 1.2 days per rem. However, it should be noted that such upper bound estimates may be high by up to a factor of 5 for low dose rates (less than 4 rem/day)..."

19. The EPA estimated 12 to 18 years in their "Background Report Proposed Federal Radiation Protection Guidance for Occupational Exposure," Office of Radiation Programs, United States Environmental Protection Agency Report EPA 520/4-81-003, p. 67, January 16, 1981.

We have rounded their range off to 15 years loss of life caused by radiation induced cancer. Calculations by Charles Willis of the NRC yield the same result.

20. Bernard L. Cohen and I-Sing Lee, "A Catalog of Risks," *Health Physics*, Vol. 36, pp. 707-722, June 1979.

21. Toxic Substances Strategy Committee, *Toxic Chemicals and Public Protection*, Council on Environmental Quality, Washington, D.C., p. xiii, 1980.

CEQ estimates that roughly 20% of all cancer deaths are associated with carcinogens in the workplace. Twenty percent of 2000 cancers per 10 000 people equals 400 cancers per 10 000 workers. This is a very rough estimate.

22. UNSCEAR Report (Reference 16), 1977, p. 429.

23. International Commission on Radiological Protection, *Problems Involved in Developing an Index of Harm*, ICRP Publication 27, Pergamon Press, New York, paragraphs 33 and 49, 1977.

24. Data from Edwin Silverberg, American Cancer Society, New York, 1980.

25. T.F. Mancuso, A. Stewart and G. Kneale, "Radiation Exposures of Hanford Workers Dying from Cancer and other Causes," *Health Physics*, Vol. 33, pp. 369-385, 1977.

T. Najarian and T. Colton, "Mortality from Leukemia and Cancer in Shipyard Nuclear Workers," *Lancet*, Vol. 1, pp. 1018-1020, 1978.

Several scientists, such as those listed above, have claimed that the generally accepted estimates of cancer risk underestimate that risk. If their estimates are right, our estimates of cancer risk would be too low. But radiation risks would still not exceed the risks in many other occupations.

Chapter 5

1. American National Standard N432, "Radiological Safety for the Design and Construction of Apparatus for Gamma Radiography," National Bureau of Standards Handbook 136, United States Government Printing Office, Washington, D.C., paragraph 8.1.2, 1981.

2. Gamma rays are assumed to have been "hardened" by already passing through a tenth-value thickness.

3. John J. Munro, III, and Frances E. Roy, Jr., *Gamma Radiography: Radiation Safety Handbook*, Tech/Ops, Inc., Radiation Products Division, 40 North Avenue, Burlington, Massachusetts 01803, 1981.

The density of tungsten is 17.8 grams/cm^3, the density of concrete is 2.35 grams/cm^3, the density of steel or iron is 7.8 grams/cm^3, the density of lead is 11.34 grams/cm^3, and the density of uranium is 18.7 grams/cm^3.

4. *Nondestructive Testing Handbook*, third edition: Volume 4, *Radiographic Testing*, Columbus, OH: American Society for Nondestructive, 2002.

This nondestructive testing text heavily references other documents. See this volume for further bibliographic information.

Chapter 6

1. *Applied Ergonomics Handbook*, ICP Sciences and Technology Press Limited, Surrey, England, p. 19, 1974.

2. Ernest J. McCormick, *Human Factors in Engineering and Design*, 4th edition, McGraw-Hill, New York, p. 69, 1976.

3. Harold P. Van Colt and Robert G. Kinkade, editors, *Human Engineering Guide to Equipment Design*, revised edition, American Institute for Research, Washington, D.C., pp. 82 and 298, 1972.

4. NRC Regulatory Guide 8.28, "Audible-Alarm Dosimeters."

This guide discusses selection and proper use of audible alarm dosimeters.

Chapter 8

1. "NRC's Jurisdiction Over Persons Using Byproduct, Source and Special Nuclear Material in Offshore Waters Beyond Agreement States' Territorial Waters," proposed rule, Federal Register, Vol. 45, p. 71807, October 30, 1980.

Chapter 9

1. 49 CFR Section 177.825(a), effective February 1, 1982, requires placarded trucks to follow routes that minimize radiological risks. Since the greatest radiological risk from radiography cameras is the risk of delayed effects of radiation to the driver and passengers of the truck, the truck should take the quickest route to the work site.

2. Case 27, "Case Histories of Radiography Events," NRC Report, NUREG/BR-0001,Vol. 1, 1980.

Chapter 10

1. The emergency drills at Norfolk Naval Shipyard were under the direction of John Martin, formerly

radiation safety officer at Norfolk Naval Shipyard.

2. Appendix D shows that in the 10 years from 1971 to 1980, the NRC has received only three reports of a radiographer being overexposed to more than 50 mSv (5 rem) to the whole body or 750 mSv (75 rem) to the hands during source recovery operations.

Chapter 11

1. In replying anonymously to a questionnaire, 80% of the radiographers replying said they surveyed always or most of the time. Twenty percent said they surveyed when being watched. The questionnaire was submitted to 40 field radiographers in the International Union of Operating Engineers, Local 2. The questionnaire was prepared by the University of Lowell. John Munro of Tech/Ops, Inc., thinks that surveys are made in most instances. Ron Wascum of the Louisiana State program estimates 70% to 80% of the surveys are made. Mike McCormack of Chicago Bridge and Iron estimates almost 100% compliance in his company, stating that he would discharge any radiographer who did not use his survey meter.

Appendix F
Credits and Acknowledgments

Figure and Table Credits

Chapter 1

Figures 1.2, 1.3 and 1.4	Deutsches Röntgen-Museum, Remscheid, Germany.
Figure 1.5	U.S. Atomic Energy Commission, Understanding the Atom Series, *Atomic Pioneers, Book 2, From the Mid-19th to the Early 20th Century*, Ray and Roselyn Hiebert, 1971.
Figure 1.6	*The Welding Engineer*, p. 35, Sept. 1942.
Figures 1.7 and 1.8	Tech/Ops, Inc., Burlington, Massachusetts.

Chapter 2

Figure 2.2	The Royal Society, London (from C.T.R. Wilson, "Investigations on X-Rays and β-Rays by the Cloud Method," *Proceedings of the Royal Society*, Volume A104, p. 1, August 1923).
Figure 2.4	Gamma Industries, Baton Rouge, Louisiana.
Figure 2.5	Dr. Eduardo Penna-Franco and Dr. M. Emmerich, Universidade Federal do Rio de Janeiro, Brazil.

Chapter 3

Figure 3.2	*Nondestructive Testing Handbook*, third edition: Volume 4, *Radiographic Testing*, Columbus, OH: American Society for Nondestructive, 2002.
Figure 3.3	*Gamma Radiation Safety Study Guide*, second edition, Columbus, OH: American Society for Nondestructive, p. 16, 2001.
Figures 3.4	Tech/Ops, Inc., Burlington, Massachusetts.

Chapter 4

Figure 4.1	Oliver and Boyd, Publishers, Edinburgh, Scotland (from W. F. Harvey, "Review of Irradiation Effects on Cells and Tissues of the Skin," *Edinburgh Medical Journal*, Volume XLIX, No. 9, Sept. 1942, pp. 529-552 and following plates.)
Figure 4.2	Dr. Eugene Saenger, Cincinnati, Ohio (from NUREG/BR-0001, Vol. 1., 1980.
Figure 4.3	H. Jammet, Commissariat A L'Energie Atomique, Fontenay-Aux-Roses, France (from "The 1978 Algerian Accident: Acute Local Exposure of Two Children," *The Medical Basis for Radiation Accident Preparedness*, Elsevier/North-Holland, Inc., New York, p. 240, 1980.)
Figures 4.4 and 4.5	Professor Maurice H. F. Wilkins, Biophysics Department, King's College, London, England.
Figure 4.6	Dr. William F. Brandom, University of Denver, Colorado.
Figure 4.7	*Gamma Radiation Safety Study Guide*, second edition, Columbus, OH: American Society for Nondestructive p. 24, 2001.
Figure 4.8	Dr. Paul Selby, Oak Ridge National Laboratory, Oak Ridge, Tennessee (from Gary O. Fullerton, et al., eds., *Biological Risks of Medical Irradiations*, American Institute of Physics, New York, p. 9, 1980).

Chapter 5

Table 5.1	*Gamma Radiation Safety Study Guide*, second edition, Columbus, OH: American Society for Nondestructive p. 28, 2001.
Figure 5.1	*Gamma Radiation Safety Study Guide*, second edition, Columbus, OH: American Society for Nondestructive p. 29, 2001.
Figures 5.3a, 5.3b and 5.3c	Industrial Nuclear Corp, Foster City, California.
Figure 5.3d	Ray Fujimoto, Radiation Protection Bureau, Department of National Health and Welfare, Ottawa, Canada.
Figures 5.4 and 5.7	Bradley Kienlen, Entergy, St. Francisville, Lousiana.

Figures 5.5 and 5.6	Tech/Ops, Inc., Burlington, Massachusetts. Bethlehem Steel Corp., Sparrows Point Shipyard, Baltimore, Maryland.
Figure 5.13	*Nondestructive Testing Handbook*, third edition: Volume 4, *Radiographic Testing*, Columbus, OH: American Society for Nondestructive, 2002.

Chapter 6

Figures 6.1a and 6.4	Dosimeter Corporation of America, Cincinnati, Ohio.
Figures 6.1b, 6.1d, 6.2, 6.3a	Bradley Kienlen, Entergy, St. Francisville, Lousiana.
Figures 6.1c, 6.1e 6.3b, 6.5 and 6.7	*Nondestructive Testing Handbook*, third edition: Volume 4, *Radiographic Testing*, Columbus, OH: American Society for Nondestructive, 2002.
Figure 6.6	Siemens Health Physics Services, Des Plaines, Illinois.
Figures in problem	Eberline Instrument Corporation, Santa Fe, New Mexico, and Dosimeter Corporation of America, Cincinnati, Ohio.

Chapter 7

Figures 7.1a, 7.2a, 7.2b	Bradley Kienlen, Entergy, St. Francisville, Lousiana.
Figure 7.1b	*Nondestructive Testing Handbook*, third edition: Volume 4, *Radiographic Testing*, Columbus, OH: American Society for Nondestructive, 2002.
Figure 7.3	Source Production & Equipment Co., St. Rose, Louisiana.
Figure 7.4	Tech/Ops, Inc., Burlington, Massachusetts.
Figures 7.5a, 7.5b, 7.5c and 7.6	Bethlehem Steel Corp., Sparrows Point Shipyard, Baltimore, Maryland.

Chapter 8

Figure 8.1	Dosimeter Corporation of America, Cincinnati, Ohio.
Figure 8.2	Tech/Ops, Inc., Burlington, Massachusetts.

Chapter 9

Figures 9.1 and 9.6	Tech/Ops, Inc., Burlington, Massachusetts.
Figures 9.2, 9.3. 9.4 and 9.5	Gamma Industries, Baton Rouge, Louisiana.
Figures 9.7 and 9.8	Bradley Kienlen, Entergy, St. Francisville, Lousiana.
Figures 9.9, 9.10 and 9.11	Roger Broseus, National Institutes of Health, Bethesda, Maryland.
Figure 9.12	Automation Industries, Phoenixville, Pennsylvania.
Figure 9.13	Gulf Nuclear, Webster, Texas

Chapter 10

Figure 10.2	Tech/Ops, Inc., Burlington, Massachusetts.

Chapter 11

Figure11.1	Bethlehem Steel Corp., Sparrows Point Shipyard, Baltimore, Maryland.
Figure 11.2	Bradley Kienlen, Entergy, St. Francisville, Lousiana.
Figure 11.3	Don Homey, California Department of Health Services, Sacramento, California.

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