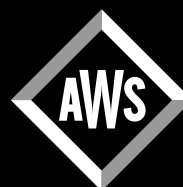


RADIOGRAPHIC INTERPRETER TEXTBOOK



American Welding Society®

EDUCATION SERVICES

Documents
Document Sharing Hub

Radiographic Interpreter Textbook

Edition – May 9, 2016

DISCLAIMER

The American Welding Society, Inc. assumes no responsibility for the information contained in this publication. An independent, substantiating investigation should be made prior to reliance on or use of such information.

International Standard Book Number:
American Welding Society
8669 NW 36 Street, #130, Miami, Florida 33166
© 2016 by American Welding Society
All rights reserved
Printed in the United States of America

Photocopy Rights. No portion of this document may be reproduced, stored in a retrieval system, or transmitted in any form, including mechanical, photocopying, recording, or otherwise, without the prior written permission of the copyright owner.

Authorization to photocopy items for internal, personal, or educational classroom use only or the internal, personal, or educational classroom use only of specific clients is granted by the American Welding Society provided that the appropriate fee is paid to the Copyright Clearance Center, 222 Rosewood Drive, Danvers, MA 01923, (978) 750-8400; www.copyright.com.



American Welding Society

Radiographic Interpreter Textbook

Table of Contents

CHAPTER 1

Radiographic Interpretation and the Radiographer Interpreter	1
Introduction.....	1
Radiography and Weld Process Control	2
Radiography Is Not an Exact Science	2
Key Elements of an Effective Radiographic Examination	3
Qualification Requirements of the Radiographic Interpreter	3
Education	4
Training	4
Experience	4
Examinations	4
Visual Acuity	4
History of Radiography.....	4
Today's State of Radiography	6
Radiography in the Future	7
Producing the Radiograph.....	7
Advantages and Disadvantages of Radiography.....	9
Advantages of Radiography	9
Disadvantages of Radiography.....	9
Chapter 1 Review Questions	10
Chapter 1 Answer Key	13

CHAPTER 2

Radiation and Radiographic Image Formation	15
The Basic Radiographic Process	15
Electromagnetic Radiation.....	15
The Atom	16
Generation of X-rays.....	17
Radiation Energy and Intensity	18
X-ray Equipment	18

Comparison of X-ray and Gamma Ray Equipment.....	19
Radioactive Isotopes and Their Characteristics	19
Energy Levels	19
Radiation Intensity	19
Source Activity	20
Half Life	20
Source Exposure Devices.....	20
Comparing Gamma Rays	21
Interaction of Radiation with Matter	21
Introduction	21
Absorption.....	21
Photoelectric Effect	22
Compton Effect.....	22
Pair Production.....	22
Chapter 2 Review Questions	24
Chapter 2 Answer Key	29

CHAPTER 3

Radiographic Film Processing and Viewing.....	31
Structure of Industrial X-ray Film.....	31
Film Base.....	31
Adhesive Layer	32
Emulsion	32
Protective Layer	32
Types of Film.....	32
Film Storage.....	33
Film Packaging	34
Boxed Films	34
Envelope Packed	34
Roll Pack (Ready Pack)	34
Darkrooms and Film Processing	34
The Darkroom.....	34
Film Processing.....	35
Manual Processing.....	35
Developer.....	35
Fixer	36
Wash	36
Drying	37
Automatic Processing.....	37
Archiving of Radiographs.....	38
Film Viewing Equipment and Conditions	39
Chapter 3 Review Questions	42

Chapter 3 Answer Key	46
CHAPTER 4	
Weld Joint Design and Terminology.....	49
Introduction	49
Types of Joints	49
Elements of the Weld Joint	51
Types of Welds	52
Groove Welds	52
Fillet Welds	52
Elements of Completed Welds	52
Terms Relating to Groove Welds	53
Terms Relating to Fillet Welds	53
Terms Relating to Weld Fusion.....	54
Terms Relating to Weld Penetration	55
Terms Relating to Fillet Weld Size.....	56
Summary.....	56
Chapter 4 Review Questions	58
Chapter 4 Answer Key	62
CHAPTER 5	
Welding Processes	65
Introduction.....	65
Welding Processes.....	67
Shielded Metal Arc Welding (SMAW).....	67
Gas Metal Arc Welding (GMAW)	69
Flux Cored Arc Welding (FCAW)	71
Gas Tungsten Arc Welding (GTAW)	72
Submerged Arc Welding (SAW).....	73
Safety in the Welding Area.....	74
Chapter 5 Review Questions	76
Chapter 5 Answer Key	81
CHAPTER 6	
Weld and Base Metal Discontinuities and Casting Discontinuities	83
Introduction	83
Common Discontinuities.....	85
Cracks.....	85
Underbead Cracking	86
Incomplete Fusion	87
Incomplete Joint Penetration	89
Inclusions.....	90

Porosity	91
Undercut	94
Underfill	94
Weld Reinforcement.....	95
Arc Strikes	96
Spatter	96
Casting Discontinuities.....	97
Gas Porosity.....	98
Sand and Slag Inclusions	98
Shrinkage	98
Cracks.....	99
Hot Tears.....	99
Inserts.....	99
Mottling	100
Other Conditions.....	100
Cold Shuts.....	100
Core Shift	100
Misruns	100
Surface Irregularities	100
Chapter 6 Review Questions	101
Chapter 6 Answer Key	110

CHAPTER 7

Factors Affecting Radiographic Sensitivity	113
Introduction	113
Radiographic Sensitivity	114
Radiographic Contrast.....	114
Radiographic Density.....	115
Radiographic Definition	115
Subject Contrast.....	116
Radiation Energy	116
Thickness Variations.....	117
Density Variations	118
Scatter Radiation.....	118
Film Contrast	119
Film Type.....	120
Processing.....	120
Radiographic Density and the Film Characteristic Curve.....	121
Intensifying Screens	123
Radiographic Definition	124
Geometric Factors	124
Geometric Unsharpness	124

Focal Spot or Source Size.....	125
Source-to-Film Distance (SFD)	125
Object-to-film distance (OFD)	125
Screen/Film Contact	125
Motion.....	126
Film Graininess.....	126
Radiation Energy.....	126
Intensifying Screens	126
Film Processing.....	127
Image Quality Indicators (Penetrameters)	127
Types of Image Quality Indicators	127
Hole Type Image Quality Indicators	127
Wire Type Image Quality Indicators.....	128
Selection of IQI	128
Placement of IQI.....	129
Chapter 7 Review Questions	131
Chapter 7 Answer Key	136

CHAPTER 8

Radiographic Techniques and Exposure Calculations.....	139
Introduction	139
Establishing a Technique.....	139
Source of Radiation	139
Test Specimen Characteristics	140
Required Sensitivity.....	140
Film Type.....	141
Single Film vs. Multiple Film Techniques	141
Intensifying Screens	142
Energy Level.....	142
Geometric Arrangement.....	142
Geometric Unsharpness	142
Exposure Arrangements	142
Layout of Weld for Radiography.....	145
X-ray Exposure Calculations	147
Gamma Ray Exposure Calculations.....	148
Determination of Defect Depth.....	150
Stereoradiography.....	150
Parallax Technique	151
Summary.....	151
Chapter 8 Review Questions	154
Chapter 8 Answer Key	160

CHAPTER 9

Reading the Radiograph	163
Three Major Aspects of Radiographic Film Interpretation	163
Determine the Quality	163
Analyze the Image	164
Interpretation of Indications	164
False Indications (Film Artifacts)	165
Artifacts Occurring Before Processing	165
Artifacts Occurring during Processing.....	166
Artifacts Occurring after Processing.....	167
Nonrelevant Indications	167
Relevant Indications.....	168
Report the Results.....	168
Summary.....	169
Chapter 9 – Review Questions	173
Chapter 9 Answer Key	178

CHAPTER 10

Radiation Safety	181
Introduction	181
Radiation: What Is It?.....	181
Ionizing and Non-ionizing Radiation.....	182
What Is the Effect of Radiation?	182
Who Is Responsible?	182
How Can Exposure to Radiation Be Minimized?	183
Time.....	183
Distance	183
Shielding	183
Things to Remember	185
Personnel Monitoring.....	185
Film Badges	185
Thermoluminescent Dosimeters (TLDs)	185
Pocket Dosimeters.....	186
Alarming Rate Meter.....	186
Survey Meters.....	186
Posting of Restricted Areas	187
Summary.....	188
Chapter 10 Review Questions	189
Chapter 10 Answer Key	192
Glossary of Terms Relating to Radiography.....	195



CHAPTER 1

Radiographic Interpretation and the Radiographer Interpreter

INTRODUCTION

This course is designed to provide a basic foundation of knowledge for the Radiographic Interpreter (RI) and to prepare the RI for the American Welding Society's Radiographic Interpreter Certification Examinations as delineated in AWS B5.15, "Specification for Qualification of Radiographic Interpreters."

Radiographic testing is a volumetric nondestructive test (NDT) method used to assure soundness of materials and welds. Depending upon how well technical control is applied in producing the radiograph, the resulting radiographs may contain much information, or very little information about the soundness of the test specimen. It must be remembered that soundness does not mean perfection; most welds contain discontinuities to some degree. The determination as to whether a discontinuity is serious enough to be classified as a defect is the responsibility of the Radiographic Interpreter (RI).

AWS A3.0, "Standard Welding Terms and Definitions," defines a discontinuity as an interruption of the typical structure of a material, such as a lack of homogeneity in its mechanical, metallurgical, or physical characteristics. A defect is defined as a discontinuity or discontinuities that by nature or accumulated effect render a part or product unable to meet minimum applicable acceptance standards or specifications. The term designates rejectability.

There are occasions when reading radiographs in which an indication on a radiograph may appear to be nothing more than a surface irregularity; however, its appearance may also be similar to that of a weld discontinuity. In these situations the RI will need to check the surface of the weld and the adjacent base metal visually before making a decision.

If no surface irregularity corresponding to the indication on the radiograph is found, the RI interprets and evaluates the indication as a weld discontinuity. However, if a surface irregularity corresponding to the indication on the radiograph is found, the RI indicates on the radiographic report that the indication is due to a surface irregularity. No disposition is necessary, as most

codes address surface conditions in the visual inspection acceptance criteria, not the radiographic acceptance criteria; therefore, the evaluation is the responsibility of the CWI, not the RI.

RADIOGRAPHY AND WELD PROCESS CONTROL

Although one generally thinks of radiography as a tool for determining the soundness of welds, it can also be a valuable tool in weld process control. The radiographic interpreter must be aware not only of discontinuities that might be present in the weld, but also trends or repetitive conditions that might indicate some lack of process control. For example, when reading the radiographs of a number of piping welds (all of the same material and pipe size) slag inclusions may be discovered in approximately the same location on a number of weldments. Even though the slag inclusions may be acceptable, this might indicate a problem with process control. Poor tie-ins in the same location may also indicate a process control problem.

The next step is to determine if the condition is prevalent with only one welder, or if it occurs with all welders. If it occurs with only one welder, then it indicates a welder

technique problem; however, if it occurs with several welders, it may indicate a procedure problem. For example, the condition may occur in a location where the welder has limited access. Whatever the case, there is a recurring issue that needs attention before it becomes a serious problem.

As he reads the radiographs, the RI must always gather as much information as possible from the radiograph and report everything he detects, even though the conditions may be acceptable or may not even be addressed in the applicable code or specification. It is always advisable to submit, in addition to the written radiographic report, a verbal report to the cognizant engineer. Written reports are not always read in a timely manner by the individuals who can make use of this information.

RADIOGRAPHY IS NOT AN EXACT SCIENCE

Radiographic Interpretation is not an exact science, but rather something of an art. Some consider it a combination of art and science. The basic principles of radiation and the principles concerned in producing a radiograph involve science, while the interpretation and evaluation of the radiographic image is more of an art. This art cannot be

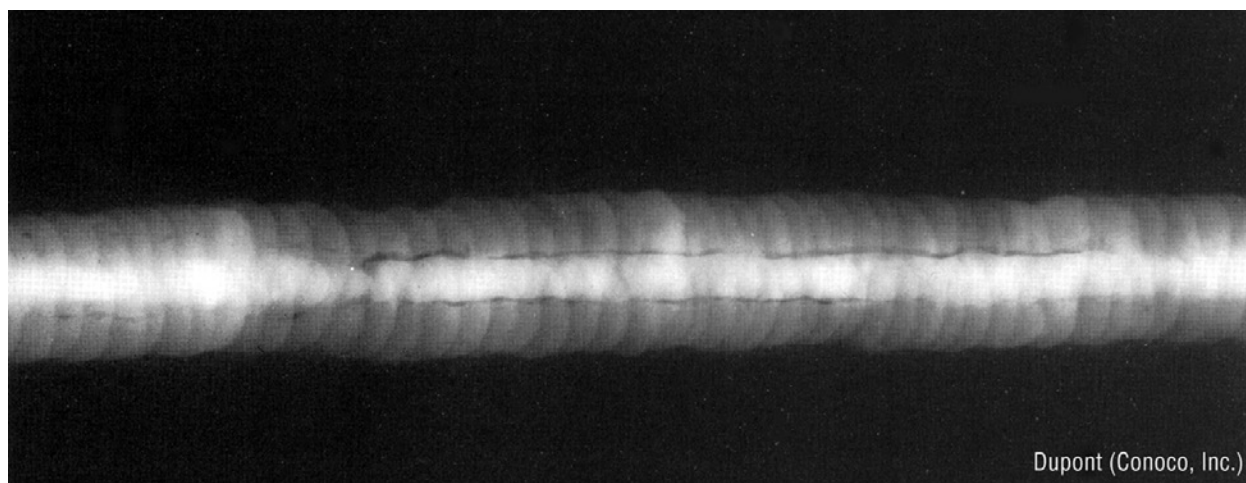


Figure 1.1. Sample Radiograph of a Weld



fully learned in a classroom. Although this course will provide a basic foundation, many hours must be spent reviewing radiographs in order to develop proficiency in radiographic interpretation. With the increasing concern for product quality, product reliability, safety, liability and economics, as well as other factors, the role of the radiographic interpreter takes on even greater importance.

Although the individual interpreting the radiographs may not be qualified as a radiographer, he must have knowledge and understanding of many aspects of radiography, similar to those of the radiographer. The Radiographic Interpreter must be familiar with some of the fundamental aspects of radiography, such as:

- ◇ the basic principles of radiography
- ◇ radiographic techniques
- ◇ X-ray films and their characteristics
- ◇ sources of radiation
- ◇ sensitivity, contrast, and definition
- ◇ film processing and associated problems
- ◇ welding processes
- ◇ weld joint designs
- ◇ weld metal discontinuities
- ◇ base metal discontinuities
- ◇ radiographic appearance of weld and base metal discontinuities
- ◇ specific code requirements for radiography and their acceptance criteria

These will be discussed in detail in the following chapters.

KEY ELEMENTS OF AN EFFECTIVE RADIOGRAPHIC EXAMINATION

The Radiographic Interpreter must have a good quality radiograph in order to effectively fulfill his responsibilities. The ra-

diographer is responsible for the quality of the radiograph produced, and must utilize proper techniques in order for the radiographic test to be effective. The RI must assess the effectiveness of the radiographic technique to produce a radiograph with acceptable quality.

The key elements of an effective radiographic test include:

1. The test must be performed by a qualified radiographer, following an approved radiographic procedure.
2. The radiograph must use a suitable source of radiation, either X-ray or gamma ray, that produces a beam of penetrating radiation with suitable energy and intensity.
3. The beam of penetrating radiation must be altered or modified as a result of discontinuities in the material.
4. The test must use the proper X-ray film for recording the variations in the radiation penetrating the test specimen.
5. The exposed film must be properly processed.
6. Interpretation and evaluation of the recorded image must be performed by a qualified interpreter utilizing the applicable codes, standards and specifications.

QUALIFICATION REQUIREMENTS OF THE RADIOGRAPHIC INTERPRETER

The Radiographic Interpreter Certification is issued by AWS to those qualified individuals who successfully complete the examination for certification. This AWS RI certification is a transportable certification, and as of the date of this writing, is the only certification of its kind offered in the USA.

AWS B5.15, "Specification for the Qualification of Radiographic Interpreters," establishes

the duties and capabilities of the Radiographic Interpreter in Section 5 - Functions. The qualification requirements are covered in Section 6 - Education, Training, and Experience Requirements. The examinations for certification are in Section 7- Examination Requirements, and the vision requirements are found in Section 8- Visual Acuity.

EDUCATION

The individual must hold a valid high school diploma or a General Equivalency Diploma (GED).

TRAINING

The individual must have completed a minimum of 40 hours of organized training in radiographic interpretation/examination that included the topics listed in the body of knowledge as specified in Section 9 of AWS B5.15.

EXPERIENCE

The individual must have a minimum of one year experience as a company certified or nationally certified individual in radiographic interpretation of media or experience working under the direct supervision of such an individual. There are provisions whereby up to a maximum of six months of experience may be substituted by post high school NDE or weld inspection education, experience as a certified weld inspector using NDE methods other than radiography, and/or experience teaching NDE weld inspection.

EXAMINATIONS

The candidates must successfully complete three examinations: General Knowledge Examination, Code Knowledge Examination, and Practical Examination.

The General Knowledge Examination is a written, multiple choice examination covering all topics listed in the body of knowledge. This includes welding metallurgy, mathematics, radiographic theory, film selection, film processing, film handling and storage, and codes, specifications and other standards.

The Code Knowledge Examination is a written, multiple choice, open-book examination covering information related to radiographic quality and film interpretation found in industry standards from AWS, ASME, API, ASNT and others.

The Practical (Film Interpretation) Examination is a written, multiple choice examination involving interpreting a minimum of ten radiographs to a code, specification, or other standard.

A minimum grade of 70% must be achieved on each of the examinations, and a composite grade (averaging the three scores) of at least 80% must be achieved.

VISUAL ACUITY

The candidate must have the ability to read a minimum of the Jaeger Number 2 letters, or better, at a minimum distance of twelve inches, with at least one eye.

HISTORY OF RADIOGRAPHY

On the night of November 9, 1895, Wilhelm Conrad Roentgen, Professor of Physics at Wurzburg University in Germany, was conducting experiments using a partially evacuated glass Hittorf-Crookes tube to study cathode rays (i.e., electrons). In his darkened laboratory, when he energized the tube, which he had covered with thin black cardboard, he observed a fluorescent glow from a paper screen coated with barium platinocyanid on a nearby table.

Röntgen immediately determined that the fluorescence was caused by invisible rays





Figure 1.2 Wilhelm Roentgen

could expose a photographic plate. Roentgen took the first radiograph, which revealed the bone structure of Mrs. Roentgen's hand.

Less than a month after the announcement of Roentgen's discovery, several medical radiographs had been made in Europe and the United States which were used by surgeons to guide them in their work.



Figure 1.3 X-ray from 1896

For his discovery, Röntgen received the first Nobel Prize in physics in 1901. Soon after the discovery of X-rays, French scientist Henri Becquerel discovered natural radioactivity. Becquerel discovered this phenomenon in 1896, while investigating the properties of fluorescent minerals. In his studies, he utilized photographic plates to record this fluorescence. He had stored some uranium compound in a drawer with his photographic plates.

originating from the Hittorf-Crookes tube. He realized he had discovered a new type of radiation which he called X-rays because of their unknown nature. Roentgen found that X-rays could penetrate cardboard, wood, a book, and thin aluminum. He discovered the X-rays

Later when he developed these plates, he discovered that they were fogged (exhibited exposure to light). Becquerel concluded that the uranium compound gave off a type of radiation that could penetrate heavy paper and expose photographic film. Becquerel had discovered radioactivity, the spontaneous emission of radiation by a material. For his discovery of radioactivity, Becquerel was awarded the 1903 Nobel Prize for physics.

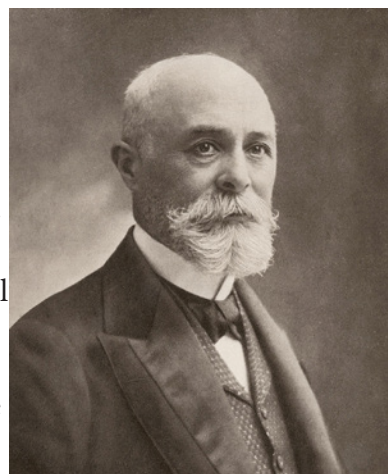


Figure 1.4 Henri Becquerel

Polish scientist Marie Curie and her husband, Pierre Curie, a French scientist, then became interested in and began investigating the phenomenon of radioactivity recently discovered by Henri Becquerel (the term radioactivity was coined by Marie). After chemical extraction of uranium from the ore, Marie noted the residual material was more "active" than the uranium itself. She concluded that the ore contained, in addition to uranium, new



Figure 1.5 Pierre and Marie Curie

elements that were also radioactive. This led to the discoveries of the radioactive elements polonium and radium. In 1903, the Curies were awarded a Nobel Peace Prize for their discoveries.

Radium became the initial industrial gamma ray source. Using a radium source, castings up to 10 inches thick could be radiographed.

During World War II, industrial radiography increased tremendously because it was used in the Navy's shipbuilding program. Manmade gamma ray sources such as cobalt and iridium became available in 1946. These new sources were far stronger than radium, were much less expensive, and rapidly replaced radium as the gamma ray source used for industrial radiography.

TODAY'S STATE OF RADIOGRAPHY

Although there have been many advances in technology, radiography has changed little from the early days of its use. A type of shadow image is still captured on film, using procedures and processes similar to those inspectors were using in the early 1900s. Today, however, professionals are able to generate images of higher quality and greater sensitivity through the use of improved films with a larger variety of film grain sizes. Film processing has evolved to an automated state producing

more consistent film quality by removing manual processing variables.

Technological advances also have provided industry with smaller, lighter, and very portable equip-

ment that produce high quality X-rays. The use of linear accelerators provides a means of generating extremely short wavelength, highly penetrating radiation. While the process has changed little, technology has evolved, allowing radiography to be widely used in numerous areas of inspection.

Since 1970, industry has seen the development of micro-focus radiography, real time imaging systems, image enhancement using computers, digitization of radiographic film, and digital filmless radiography.

Electronics and computers now allow technicians to capture images digitally. This use of "filmless radiography" provides a means of capturing an image and digitally enhancing it, sending the image anywhere in the world, and archiving an image that will not deteriorate with time. Shown above is an example of a computed radiographic system and an example of a CR image.

Radiography has seen expanded usage in industry to inspect not only welds and castings, but also items such as airbags, electronic components, composite materials and canned food products. Radiography has found use in metallurgical material identification, corrosion detection, and security systems at airports and other facilities.

Gamma ray inspection has also changed considerably since the Curies' discovery of radium. The manmade isotopes of today are far stronger and offer the technician a wider range of energy levels and half-lives. The radiographer can select Cobalt 60, which will effectively penetrate very thick materials, or select a lower energy isotope such as Thulium 170, which can be used to inspect plastics and very thin or low-density materials. Today, gamma rays find wide application in industries such as petrochemicals, casting, welding, and aerospace.



Figure 1.6 Digital Filmless Radiography





Figure 1.7 Digital Radiography

RADIOGRAPHY IN THE FUTURE

Although many of the methods and techniques developed over a century ago remain in use, computers are becoming a part of radiographic inspection. The future of radiography will certainly see many changes.

In the future, radiographers will be able to capture images of a test specimen in digitized form and e-mail them to their customer when the inspection has been completed. Evaluation of the image also will probably be left to computers. Inspectors may capture a digitized image, download the image into a computer, and wait for a printout of the image with an accept/reject report. Systems will be able to scan a part and present a three-dimensional digital image, helping the radiographer locate the discontinuity within the test specimen.

PRODUCING THE RADIOGRAPH

The basic method of producing a radiograph is shown in Figure 1.9. A radiation source (X-ray or gamma ray) is placed on one side of a test object, and an X-ray film is placed as close as possible to the other side of the test object.

As the radiation penetrates the test object, it is partially absorbed by the material in a way that differing quantities of radiation penetrate through the test object and create exposure on the film. The greater the amount of radiation exposing the film, the darker the image created on the radiograph. Therefore, under thin areas of the test object, the radiograph is darker (higher radiographic density), while under thick areas the radiograph is lighter (low radiographic density).

Likewise, if a radiograph is taken of an object made from different materials, such as a dissimilar metal weld, there will be variations in the radiographic density observed on the radiograph. Figure 1.8 illustrates this principle: four specimens having different material densities (lead, copper, steel and aluminum) have been radiographed on one film. Due to

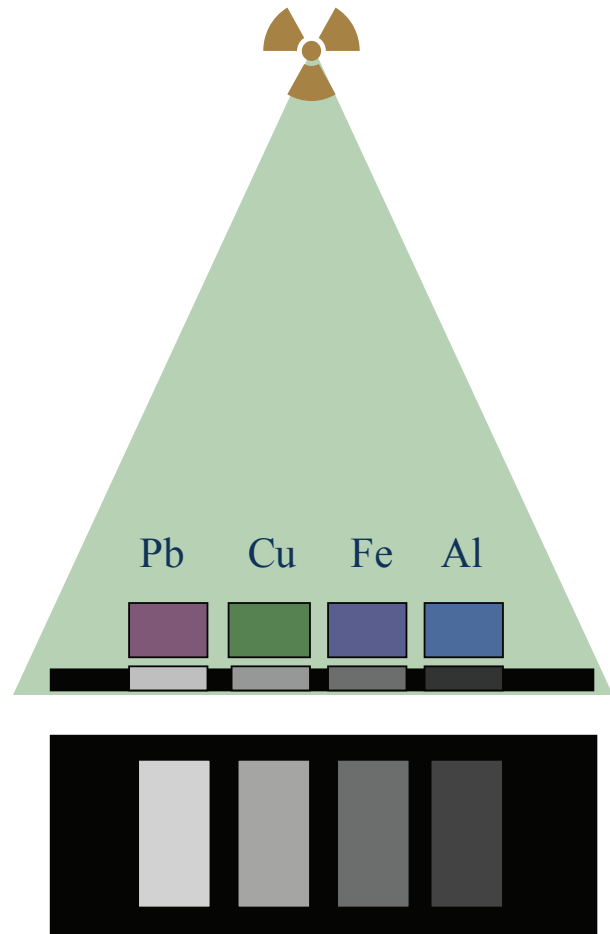


Figure 1.8 Effect of Material Density

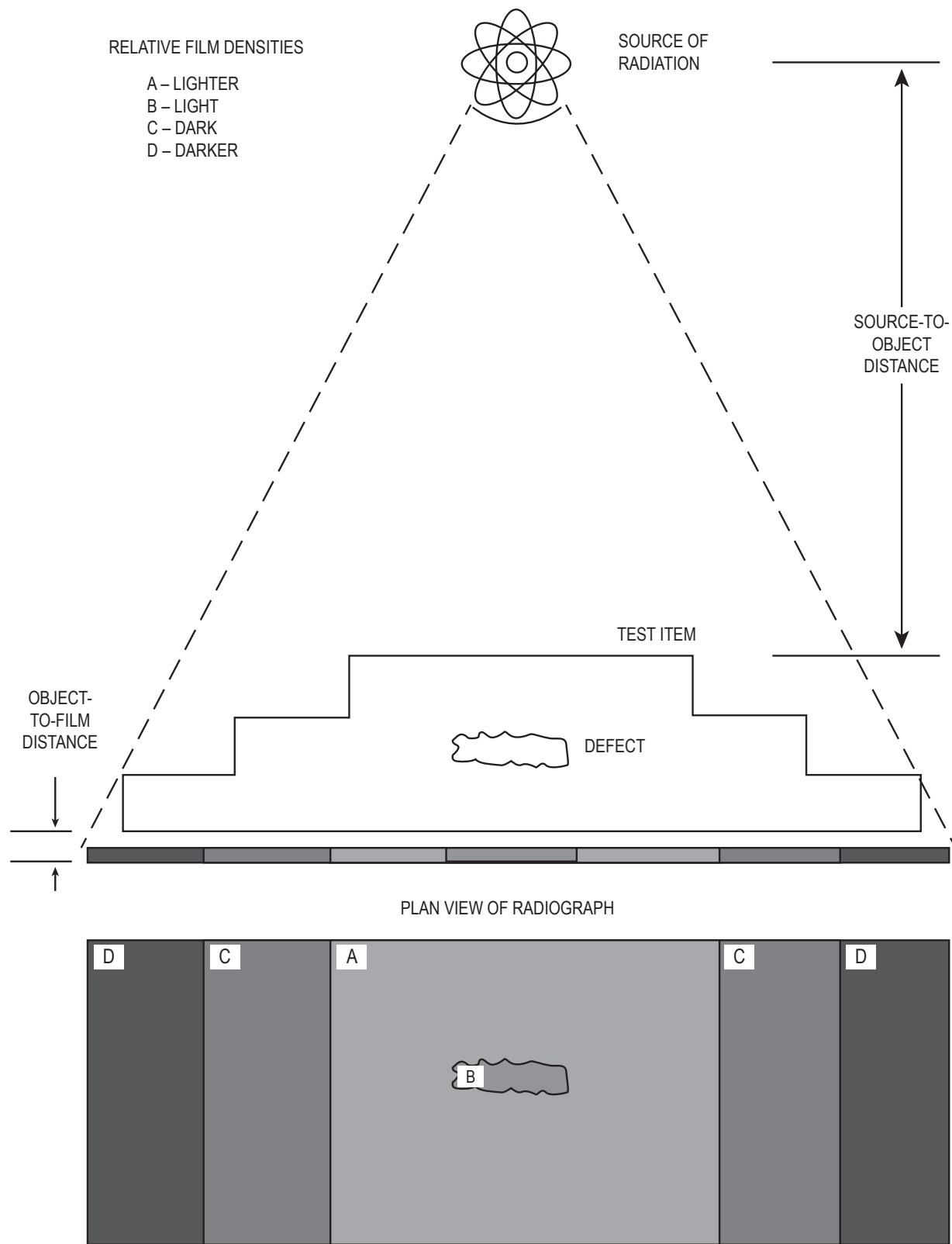


Figure 1.8 The Radiographic Process and Effect of Material Thickness

the difference in the four materials' absorption characteristics, the resulting radiographic density varies for the four specimens.

If there is a loss of material due to a discontinuity such as a crack, void, porosity, etc. the radiographic image will also be darker. If there is a non-metallic inclusion (e.g. slag) in a weld, the image will also be darker, but if there is a high material density inclusion such as tungsten, the image will be lighter.

In order to properly interpret the radiograph, the RI must understand the basic principles of radiography and how they affect the image produced on the film. These principles will be discussed in the following chapters, which should be studied carefully.

ADVANTAGES AND DISADVANTAGES OF RADIOGRAPHY

It is important to understand that none of the nondestructive test methods will find all discontinuities that may be present in a specimen. Each NDT method complements other methods; that is, a discontinuity that may not be detected by one method may be easily found by another. For example, radiography usually will not reveal laminations in plate or pipe; however, these are easily detected using a straight beam ultrasonic test.

Each NDT method has advantages, disadvantages, or limitations, and it is important to understand not only the advantages of the NDT method, but also the disadvantages or limitations of the method. Listed below are the advantages and limitations of radiography.

ADVANTAGES OF RADIOGRAPHY

- a. It is a volumetric Nondestructive Test Method.
- b. Both X-ray and gamma ray equipment is available.
- c. It can be used on most materials.
- d. It provides a permanent record, the radiograph.
- e. Radiography detects internal flaws.
- f. It gives a direct image of flaws on the radiograph.
- g. It can be used for in-process, final, or in-service inspections.
- h. Radiography can be used to check for correct assembly.
- i. It can be used for pipe wall thickness measurements.
- j. Real time imaging and digital imaging systems are available.

DISADVANTAGES OF RADIOGRAPHY

- a. There is an initial high capital investment.
- b. It presents a potential radiation health hazard.
- c. Access to both sides of the object is required.
- d. It is sensitive to the orientation of discontinuities.
- e. It has limited ability to detect fine cracks.
- f. Radiography may not detect all discontinuities.
- g. Limited thickness of materials can be penetrated.
- h. It is relatively time-consuming method of inspection.
- i. There is a high operating cost.
- j. Skilled Radiographers and Radiographic Interpreters are required.

Chapter 1 Review Questions

1. A photographic record produced by the passage of X-rays or gamma rays through a specimen to expose a film is called:
 - A. A radiograph
 - B. An X-ray picture
 - C. A shadowgraph
 - D. A latent image
2. The degree of darkness on the film is called:
 - A. Film contrast
 - B. Film characteristics
 - C. Film density
 - D. Film blackness
 - E. Radiographic sensitivity
3. The thickest section of any specimen being radiographed will absorb _____ (more/less) of the radiation than the thinner sections.
4. After film has been exposed to radiation and then processed, the area of the film receiving the most radiation will be _____ (lightest/darkest).
5. On a radiograph, the thinnest section of a specimen appears _____ (darker/lighter) than the thickest area.
6. Which of the following factors will have the greatest influence on the image density of a radiograph?
 - A. The type of film used
 - B. The size of film used
 - C. The total amount of radiation striking the film
 - D. The intensifying action of the screen
 - E. The time in the developer
7. An interruption in the normal physical structure of a part would be considered:
 - A. An indication
 - B. A discontinuity
 - C. A defect
 - D. An irregularity
 - E. A flaw



8. An inclusion in a weld would appear on a radiograph as:

- A. A dark spot
- B. A light spot
- C. A generalized gray area of varying contrast
- D. Either a dark or a light indication depending on the type of inclusion
- E. A rather narrow and sharply defined, but jagged indication

9. Which of the following establishes the specific qualification requirements for a Radiographic Interpreter?

- A. NAS 410
- B. AWS B5.15
- C. AWS QC-1
- D. IRRSP
- E. All of the above

10. The initial radioisotope used for radiography was:

- A. Iridium 192
- B. Uranium
- C. Thulium 170
- D. Radium
- E. Californium 252

11. Radiography is one of the most widely used NDT methods because:

- A. It is a volumetric NDT method and it will reveal all discontinuities
- B. It is a volumetric NDT method and it provides a permanent record
- C. It is a volumetric NDT method and it is easy to perform
- D. It can be performed anywhere
- E. It is easier to interpret and evaluate results than with other NDT methods

12. X-rays were discovered by _____, and _____ discovered that uranium would expose photographic plates.

- A. Wilhelm Roentgen, and Marie Curie
- B. Wilhelm Roentgen, and Henri Becquerel
- C. Henri Becquerel, and Pierre Curie
- D. Marie Curie and Wilhelm Roentgen
- E. None of the above; uranium does not expose photographic plates or films.

13. List three key elements of a radiographic test.

14. List five advantages of radiography.

15. List five disadvantages of radiography.

16. After film has been exposed to radiation and then developed, the area of the film receiving the least radiation is _____.
A. Darkest
B. Lightest
17. A condition existing in a part that is of such size that it exceeds the limits of the acceptance criteria is referred to as:
A. An indication
B. A discontinuity
C. A defect
D. An irregularity
E. A flaw
18. While reading the radiographs of a number of welds in tubular structures the reviewer discovers recurring indications of root concavity in the same area in many of the welds. Further investigation reveals that this condition occurs with almost all of the welders. This may indicate:
A. A lack of skill and experience on the part of the welders
B. A poor fit-up
C. An improper weld rod being used
D. A problem with the welding process or the welding procedure
E. Failure of the welder to maintain the proper interpass temperature
19. A small localized area on a radiograph that has a higher density than the surrounding area would be called:
A. An indication
B. A discontinuity
C. A defect
D. An anomaly
E. A flaw
20. The radiographic indication of a tungsten inclusion appears very light on the radiograph because:
A. Tungsten absorbs less radiation than the surrounding area.
B. The tungsten inclusion is usually very small.
C. It is a subsurface discontinuity.
D. Both A and C
E. None of the above



Chapter 1 Answer Key

1. A
2. C
3. More
4. Darkest
5. Darker
6. C
7. B
8. D
9. B
10. D
11. B
12. B
13. source of radiation; test specimen; x-ray film
14. (see items on page 9)
15. (see items on page 9)
16. Lightest
17. C
18. D
19. A
20. E



American Welding Society

CHAPTER 2

Radiation and Radiographic Image Formation

THE BASIC RADIOGRAPHIC PROCESS

ELECTROMAGNETIC RADIATION

Electromagnetic radiation is waves of energy that are caused by the acceleration of charged particles. These waves of energy need no medium for propagation: they can travel through a vacuum, and their velocity in free space is constant at approximately 186,000 miles per second, the velocity (v) of light. The characteristics of electromagnetic radiation depend upon its frequency (F), the velocity (v), and the wavelength (λ).

When radiation interacts with matter, a portion is absorbed and the balance is transmitted. This interaction is complex and can debase the quality of the resulting radiographic image. The RI must be familiar with these interactions and understand how they can reduce radiographic quality and hinder the detection of potentially harmful defects.

The range of wavelengths (λ) over which electromagnetic radiation occurs is called the elec-

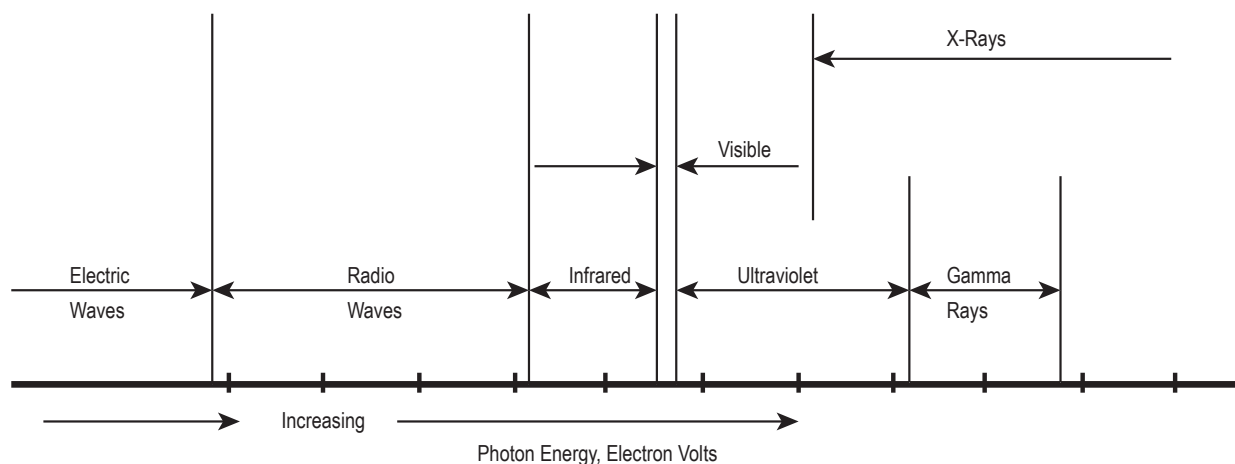


Figure 2.1 The Electromagnetic Spectrum

tromagnetic spectrum. The electromagnetic spectrum is a family of radiation types having differing wavelengths, frequencies, and energies; the velocity is constant in free space. The lower frequencies (longer wavelengths) are associated with radio, infrared, visible light and ultraviolet radiation. The higher frequencies (shorter wavelengths) are associated with X-rays and gamma rays.

X-rays and gamma rays are both forms of electromagnetic radiation and differ only in their method of production. X-rays are generated by electrical machines when electrons travelling at a high velocity collide with and interact with the target of the X-ray tube. Gamma rays are produced (emitted) during the decay of the nucleus of unstable (radioactive) atoms. General properties of X-rays and gamma rays include:

1. They are forms of electromagnetic radiation.
2. They travel in straight lines in free space.
3. They travel at the speed of light (approximately 186,000 miles per second).
4. They expose photographic films.
5. They cause fluorescence and phosphorescence in some materials.
6. They ionize matter.
7. They may be diffracted by a crystalline structure (e.g. a metal).
8. They are differentially absorbed and scattered by different materials.
9. They are undetectable by human senses.
10. They may damage or destroy living tissue.
11. They may produce genetic mutations.

THE ATOM

A basic knowledge of the structure of the atom is necessary in order to understand the principles involved in the generation of

X-rays, the emission of gamma rays during radioactive decay, and the radiographic process.

As seen in Figure 2.2, the atom consists of two distinct areas containing three basic particles. The nucleus contains protons and neutrons which are closely bonded together with great force. The proton is a heavy particle that has a unit-positive electrical charge (+1) and the neutron, about the same mass as a proton, has no electrical charge. Orbiting around the nucleus in fixed energy shells (orbits) are electrons, which have a unit-negative electrical

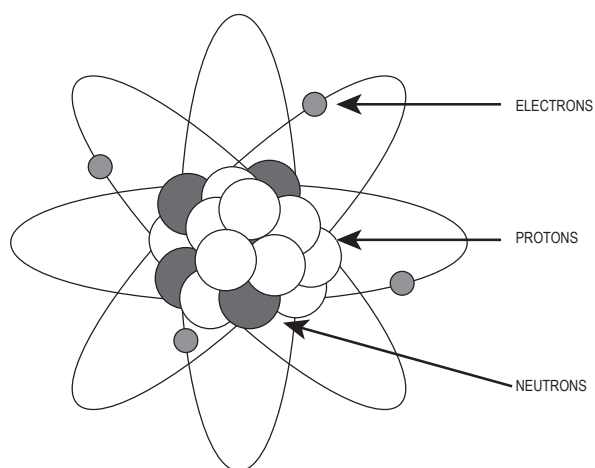


Figure 2.2 Structure of an Atom

charge (-1), and a mass which is approximately 1/1840 that of the proton. The electrons are held in orbit around the positively charged nucleus by an electrostatic field, given by the fact that unlike charges attract.

The electrons move around the nucleus in orbits or shells, starting with the innermost shell, called the K shell, and moving outwards to the L shell and so on to the Q shell. The K shell will hold two electrons, the L shell eight, the M shell 18, the N shell 32, the O shell 18, the P shell 12, and the Q shell 2. See Figure 2.3.

The number of protons in the nucleus is the atomic number (called the Z number) and identifies the type of element. If the number of protons in the nucleus changes, the atomic number changes; therefore it is an atom of a

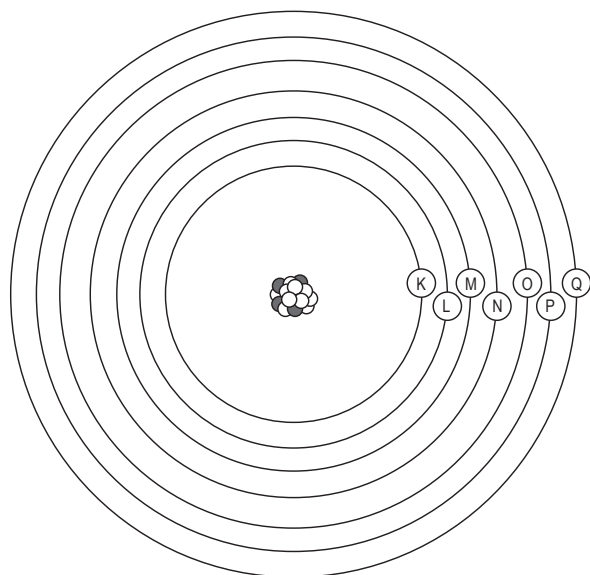


Figure 2.3 Electron Orbits

different element.

An atom is normally electrically neutral, with an equal number of electrons and protons; therefore, it has no electrical charge. Any action which upsets the normal electrical balance of the atoms which make up matter and creates ion pairs is called ionization. X-rays and gamma rays both have the ability to ionize as they interact with any form of matter. This will be discussed further in the section on the interaction of radiation with matter.

GENERATION OF X-RAYS

There are three main requirements for the generation of X-rays:

1. A source of free electrons.
2. A means of accelerating the electrons.
3. A target to receive the impact of the electrons.

In an X-ray tube (Figure 2.4) the free electrons, the first requirement for the generation of X-rays, are produced by passing a current through a tungsten filament which is part of the cathode. The resistance to the current causes the temperature of the tungsten filament to increase until it is incandescent, in a manner similar to the filament in a toaster.

As the temperature of the filament increases, there is an increase in the kinetic energy of the electrons within the tungsten filament until they have enough energy to overcome the potential barrier at the surface of the tungsten. The number of electrons emitted rises sharply with increasing temperature. This phenomenon is called thermionic emission. The free electrons produced by thermionic emission form an electron cloud around the tungsten filament.

The second requirement for the generation of X-rays is the acceleration of the electrons to a high velocity prior to colliding with the tar-

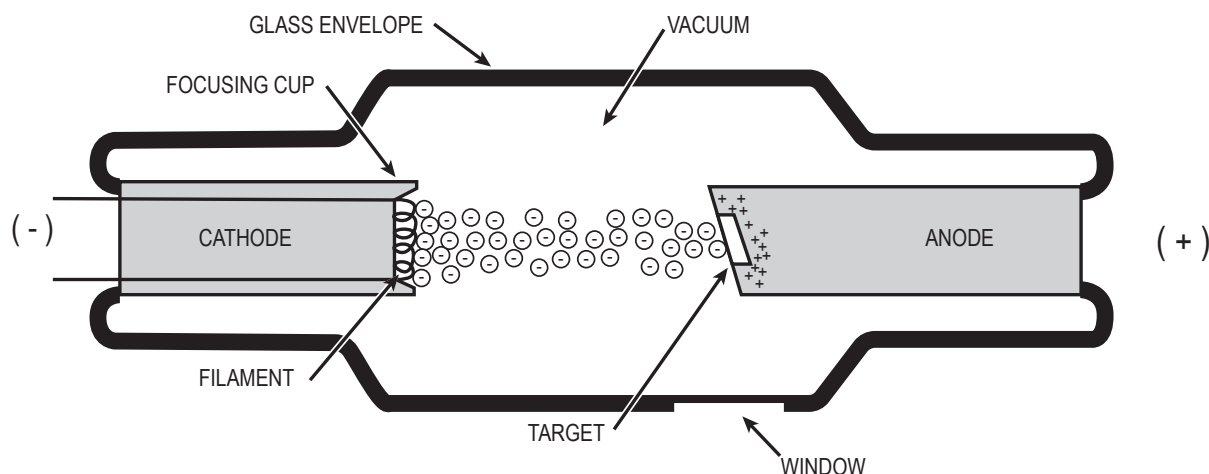


Figure 2.4 The X-ray Tube

Energy Levels	Effective Thickness Range
150 kVP	Up to 0.250"
200 kVP	0.250" to 0.50"
250 kVP	0.330" to 0.850"
300 kVP	0.350" to 2.00"
400 kVP	0.500" to 3.00"
1.0 MeV	0.800" to 4.00"
2.0 MeV	1.0" to 5.0"
6.0 to 10.0 MeV	3.0" to 16"
10.0 to 20.0 MeV	10.0" to 24.0"

Table 2.1 X-ray Energy Levels and Effective Thickness Ranges

get embedded in the face of the anode. Recognizing that unlike charges attract, if a potential difference (voltage) is established between the anode and the cathode, the negatively charged electrons will be attracted to the positively charged target, accelerating as they travel to attain kinetic energy. These electrons then collide with the target.

As the electrons collide with the target, they are slowed or stopped, depending on the type of collision occurring within the atomic structure of the target. When the electrons arrive at the target, they have a certain kinetic energy given by the kilovoltage across the tube; the greater the kV, the greater the kinetic energy. When the electrons are slowed or stopped as they collide with the target, they lose some or all of their kinetic energy. The law of conservation of energy states that energy can neither be created nor destroyed, but it can be converted from one form of energy to another. The electron's kinetic energy is converted into forms of electromagnetic radiation, but only a small portion of the energy, about 1%, is converted into X-rays. The balance of the energy is converted into visible light and heat.

RADIATION ENERGY AND INTENSITY

Radiation energy, also referred to as radiation quality, is controlled by the kilo-

voltage (kV) applied to the X-ray tube. If the radiographer increases the kV, shorter wavelength, higher energy X-rays are produced, while a reduction in kV results in production of X-rays with longer wavelengths and lower energy.

Radiation intensity, also referred to as radiation quantity, is controlled by the current applied to the X-ray tube. If the radiographer increases the tube current, measured in milliamps (mA), with no change of kV, the intensity of the radiation increases proportionally; i.e. if the mA is doubled, the intensity also doubles.

X-RAY EQUIPMENT

There is a wide variety of X-ray units available, from small portable units (with a maximum energy output of 120 kV) that can be taken into the field for remote operations, to permanently installed linear accelerators capable of producing X-rays with energy levels of 15 million electron volts (MeV). Each type of equipment has its niche in industrial radiography, and a detailed discussion of all types of X-ray equipment is not necessary.

Table 2.1 lists some different X-ray energies produced by X-ray units and the thickness range of steel that can be effectively penetrat-



ed.

COMPARISON OF X-RAY AND GAMMA RAY EQUIPMENT

Advantages of X-rays

1. Energy and intensity can be controlled.
2. The radiographs generally have more contrast and better definition.
3. The radiation can be switched off; therefore, the radiation hazard is less.
4. Periodic replacement is not required.
5. Exposure times are often shorter.

Disadvantages of X-rays

1. There is a higher initial capital expenditure for equipment.
2. Electrical supply is necessary.
3. Equipment is not as portable.
4. Lower energy X-rays produce more random scatter.
5. Lower energy limits the thickness range that can be penetrated.

Attribute	Technical Term	Controlled by...
Radiation Energy	Quality	kilovoltage (kV)
Radiation Intensity	Quantity	milliamps (mA)

RADIOACTIVE ISOTOPES AND THEIR CHARACTERISTICS

The discovery that certain naturally occurring heavier elements emit penetrating radiation was made in 1896 by Henri Becquerel. These are referred to as radioisotopes. The nuclei of the atoms of radioisotopes are unstable, and by a process of disintegration or decay become stable. The disintegration is accompanied by the emission of alpha particles or beta particles and gamma rays.

Alpha particles can be stopped by a piece of paper, and beta particles can be stopped with a thin sheet of metallic foil; therefore, they are of no practical value in industrial radiography. It is the gamma rays that are beneficial and commonly used in industrial radiography.

The earliest isotope to be used was radium, but it began to be replaced when it became possible to produce artificial radioactive isotopes that were more effective than radium as sources for radiography. The most commonly used radioisotopes for contemporary radiography are Iridium 192 and Cobalt 60; both are artificially created by a process called activation.

ENERGY LEVELS

Unlike X-rays, the energy of a radioisotope is a function of the type of radioisotope and cannot be varied or controlled. The energy of a specific isotope is constant and is expressed as an average energy. The energy levels of the commonly used radioisotopes are considerably higher than conventional X-ray machines and are suitable for radiographing thicker sections, but are unsuitable for thin steel sections or light alloys. The average energy of Iridium 192 is 0.4 MeV and 1.2 MeV for Cobalt 60.

Because the energy level determines the penetrating power, it is usual to state an effective thickness range for the various isotopes. The effective thickness for Iridium 192 is $\frac{3}{4}$ inch to 2 $\frac{1}{2}$ inches of steel, while Cobalt 60 has an effective thickness range of 1 $\frac{1}{2}$ inches to about 8 inches of steel.

RADIATION INTENSITY

The intensity (quantity) of radiation emitted from any radioisotope is dependent upon the standard dose rate for the type of isotope and the activity of the source. The standard dose rate of a radioisotope is usually

Attribute	Technical Term	Controlled by...
Radiation Energy	Quality	Choice of Source (e.g. Ir-192 or Co-60)
Radiation Intensity	Quantity	Activity of Source (measured in Curies)

expressed as Roentgens per hour at a distance of one foot per curie (RHF/Ci) or Roentgens per hour at a distance of one meter (RHM/Ci). The Standard Dose Rate for Iridium 192 is 5.3 RHF/Ci or 0.55 RHM/Ci, and 14.5 RHF/Ci or 1.35 RHM/Ci for Cobalt 60.

SOURCE ACTIVITY

The source activity is a factor the radiographer must use in determining the exposure time for radiographing a particular specimen. The activity of a source is a measure of the quantity of radiation and is related to the decay rate of the particular isotope.

The unit of measure of activity is the curie (Ci), which is defined as the quantity of a radioactive substance decaying at a rate of 3.7×10^{10} disintegrations per second (DPS). The S.I. unit is the becquerel (Bq), and one becquerel is equal to 1 disintegration per second. These definitions do not take into account the type of energy levels or the number of particles or photons per disintegration.

HALF LIFE

The rate at which a radioisotope decays is expressed in terms of its half-life, which is the time it takes for an isotope to decay to one half its original activity. The half-life for

Iridium 192 is 75 days, and the half-life for Cobalt 60 is 5.3 years. Thus after two half lives the activity is reduced to one fourth of the original activity. For example, a 100 curie Cobalt 60 source will decay to 25 curies after 10.6 years, while a 100 curie Iridium 192 source will decay to 25 curies in 150 days. As the source decays, the radiographer must increase the exposure time accordingly in order to achieve the same exposure; i.e. an exposure of a certain weld may require two minutes using 100 curie, but after 75 days the required exposure for the same weld, using the same source, requires 4 minutes, and after another seventy five days, eight minutes are required. Obviously, at some point in time the exposure time is so long as to make it impractical to utilize that source; therefore, it needs to be replaced.

SOURCE EXPOSURE DEVICES



Figure 2.6 Exposure Device



Figure 2.5 Source Pigtails

The radioactive source is sealed in a capsule attached to a flexible cable referred to as a pigtail (see Figure 2.5). The pigtail is held in the center of an S-shaped channel in an exposure device, commonly referred to as

the camera (Figure 2.6). The camera contains a shielding “pig,” usually depleted uranium, which reduces the radiation to a level that makes it safe for the radiographer to handle the camera.

During the radiographic process, a flexible cable (drive cable) is attached to one end of the pigtail so the source can be driven through a guide tube to the exposed position. With this type of exposure device, the position of the source can be set without the operator receiving any significant dose. This is the most common type of equipment used for industrial radiography.

COMPARING GAMMA RAYS

Advantages of Gamma Rays

1. No electrical or water supplies are needed.
2. Equipment is usually smaller and lighter than X-ray equipment and therefore more portable.
3. They may be used in applications with limited accessibility.
4. There is a lower initial capital expenditure for equipment.

Disadvantages of Gamma Rays

1. Energy and intensity cannot be controlled.
2. The radiographs generally have less contrast and definition.
3. Exposure times can be longer.
4. Sources must be replaced at regular intervals.
5. The radiation cannot be turned off; therefore, the radiation hazard is greater.

INTERACTION OF RADIATION WITH MATTER

INTRODUCTION

As previously discussed, X-rays and gamma rays are electromagnetic waves of energy. They travel at the speed of light as packets of wavelengths referred to as photons. Although these photons of electromagnetic radiation have no rest mass or weight and no charge, they exhibit a dual character. That is, they sometimes act like waves of energy and at other times act like particles.

As a beam of X-rays or gamma rays penetrates through matter, the intensity of the radiation is reduced by a process of absorption. Therefore, the intensity of the radiation penetrating through the matter (emergent intensity) is less than the incident radiation intensity. For a given incident beam intensity, the emergent intensity is exponentially reduced based upon the thickness of the absorbing material and a factor called the linear coefficient of absorption. The linear coefficient of absorption is dependent on the type of material and the radiation energy.

ABSORPTION

As it relates to radiography, the term absorption may be defined as the process where photons of electromagnetic radiation lose their energy as they interact with the atoms of the material being penetrated. The absorption of the photons is the result of the photon either striking an orbital electron or entering the nuclear field of the atom. In these interactions, the energy of the photon is transferred through three ionization processes. These are Photoelectric Effect, Compton Effect, and Pair Production.

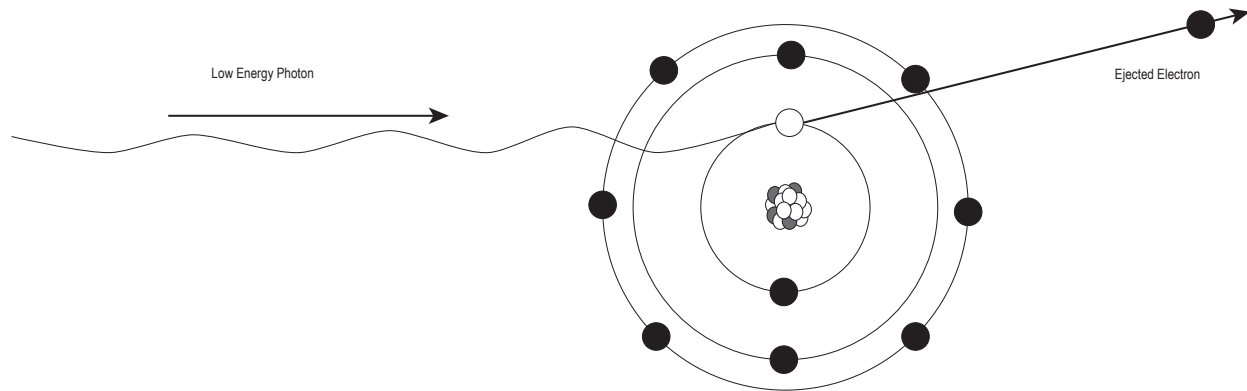


Figure 2.7 Photoelectric Effect

PHOTOELECTRIC EFFECT

The Photoelectric Effect involves the total absorption of a photon's energy. When low energy photons (0.1 MeV or less) pass through a material and a photon collides with an orbital electron, some of the photon's energy is absorbed in dislodging the electron from its orbit. The remainder of the photon energy is transferred to the ejected electron to give it kinetic energy or velocity. The photon has lost all of its energy and no longer exists. See Figure 2.7.

collides with an orbital electron, a portion of the photon's energy is absorbed in dislodging the electron from its orbit. A portion of the remaining photon energy is transferred to the ejected electron to give it kinetic energy or velocity. The photon continues, but on a different path and with less energy (referred to as Compton scatter). This process may be repeated several times until the photon's energy has been reduced to the point where the next collision results in the photoelectric effect. See Figure 2.8.

COMPTON EFFECT

The Compton Effect involves the partial absorption of a photon's energy. When a photon of higher energy (0.1 MeV to 1.0 MeV)

PAIR PRODUCTION

When photon energy is 1.02 MeV or greater, ion pairs may be produced. In this process, a very high energy photon inter-

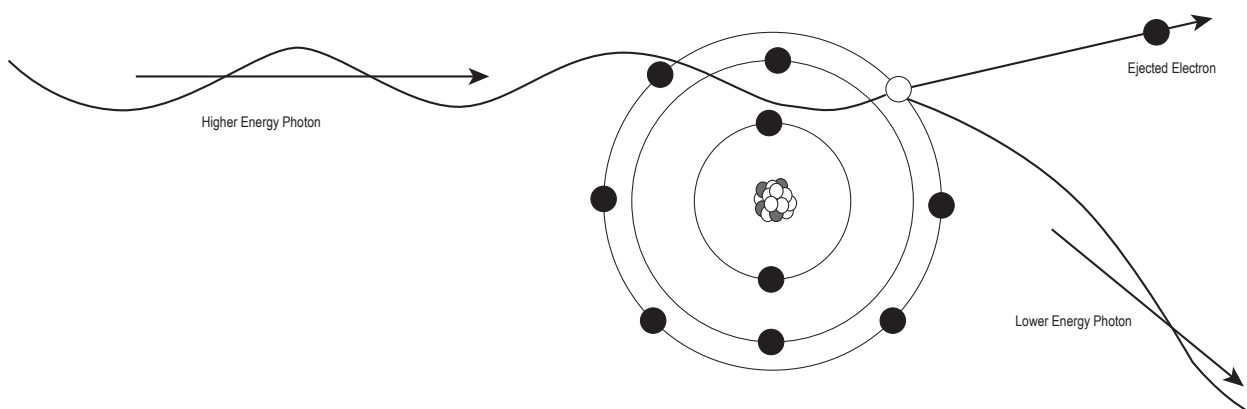


Figure 2.8 Compton Effect

acts with the field surrounding the nucleus of an atom. The photon energy is converted into an electron-positron pair. A positron has the same mass as an electron, but it has a positive charge.

The positron has a very short life because it collides with and combines with an electron, and both cease to exist and together give up their energy with the emission of two gamma photons of 0.51 MeV each. The two photons act like other low energy photons and may cause ionization by the Compton Effect and the photoelectric effect. See Figure 2.9.

It should be evident, therefore, that the absorption of X-rays and gamma rays is not a simple process in which the incident beam of radiation energy changes to another form of energy and effectively disappears.

Instead, there is some conversion to secondary X-rays of lower energy and longer wavelength traveling in a different direction from the primary beam. Much of this secondary radiation, referred to as scatter radiation, does not contribute to the radiographic image, and in fact, it actually debases the image quality because it reduces contrast and definition on the radiograph.

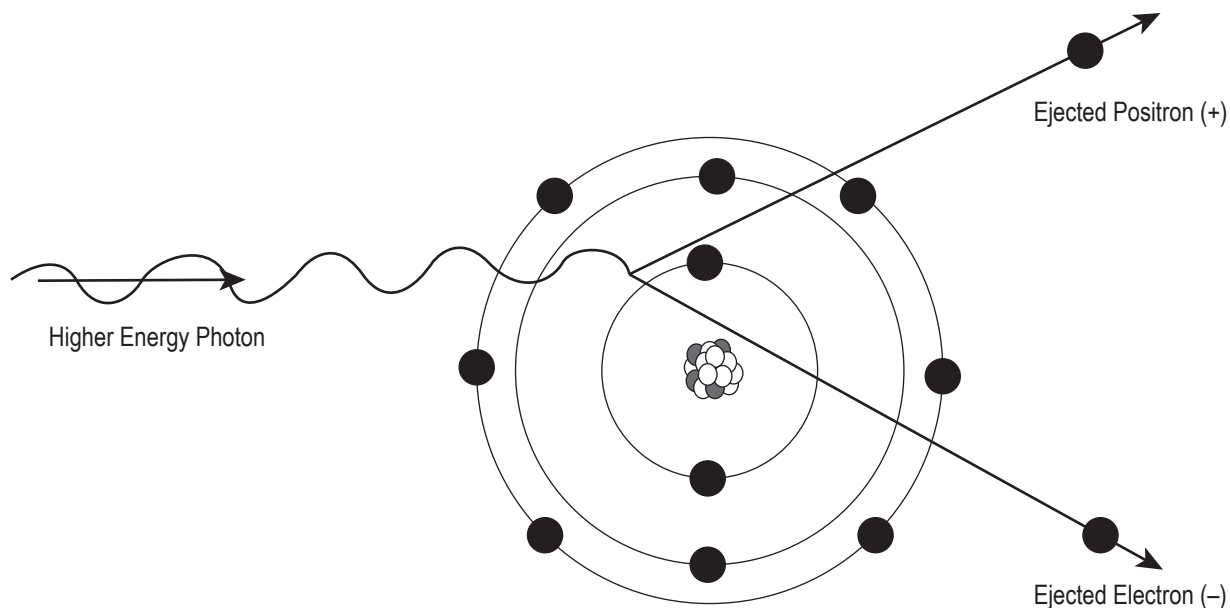


Figure 2.9 Pair Production

Chapter 2 Review Questions

1. Which of the following is an advantage of using an X-ray machine rather than a gamma ray source?
 - A. Shielding is not required.
 - B. Greater portability is possible.
 - C. Radiographs will have greater latitude.
 - D. There is the ability to control the radiation energy and the intensity.
 - E. The test can use shorter SFD's because of smaller target (source) size.
2. X-rays are generated in an X-ray tube when electrons traveling at high velocity collide with the atoms of the target material. Most of the electrons energy is converted to:
 - A. Continuous X-rays
 - B. Characteristic X-rays
 - C. Heat and visible light
 - D. Long wavelength X-rays
 - E. Penetrating radiation
3. In order to increase the intensity of X-radiation:
 - A. The tube current should be increased.
 - B. The tube current should be decreased.
 - C. The test specimen should be moved further from the film.
 - D. A lower kilovoltage should be applied to the tube.
 - E. The large focal spot should be used.
4. Radiation energy is usually expressed in terms of:
 - A. Kev or Mev
 - B. Curies per gram
 - C. Roentgens per hour
 - D. Milliroentgens per hour
 - E. Both C and D
5. What is the primary difference between X-rays and gamma rays of the same energy?
 - A. Wavelength
 - B. Frequency
 - C. Velocity
 - D. Origin
 - E. Intensity



6. When all of a photon's energy is absorbed as it collides with an electron in an atom in the test specimen, the ionization process involved is called:
- A. Photoelectric effect
 - B. Compton effect
 - C. Pair production
 - D. Total absorption
 - E. Partial absorption
7. The speed at which X and gamma rays travel is:
- A. The speed of light
 - B. The speed of sound
 - C. Varied with the wavelength
 - D. Dependent upon the type of the source
 - E. Dependent upon the energy level
8. What is the primary difference between X-rays of different energies?
- A. Wavelength
 - B. Current
 - C. Velocity
 - D. Origin
 - E. Intensity
9. X-rays and gamma rays have one thing in common: they are both forms of:
- A. Particulate radiation
 - B. Electromagnetic radiation
 - C. Microwave radiation
 - D. Cosmic Radiation
 - E. None of the above
10. Check the items that apply to X and gamma radiation:
- | | |
|--|---|
| ☐ Is a particle | ☐ Has mass |
| ☐ Ionizes matter | ☐ Speed of light |
| ☐ Harmful | ☐ High frequency |
| ☐ Electromagnetic | ☐ Long wave length |
| ☐ Has odor | ☐ Is visible |
11. What governs the penetrating power of an X-ray beam?
- A. Kilovoltage
 - B. Time
 - C. Activity
 - D. Milliamperage
 - E. Focal spot size
12. The shorter the wavelength of X and gamma rays:
- A. The higher their energy
 - B. The faster they travel
 - C. The greater their penetration power
 - D. The slower they travel
 - E. Both A and C
13. When a photon collides and interacts with the atoms in the test specimen and results in the emission of a secondary photon of lower energy level, the ionization process involved is called:
- A. Photoelectric effect
 - B. Compton effect
 - C. Pair production
 - D. Total absorption
 - E. Partial absorption

14. As the kilovoltage applied to the X-ray tube is lowered:

- A. X-rays of longer wavelength and more penetrating power are produced.
- B. X-rays of shorter wavelength and more penetrating power are produced.
- C. X-rays of shorter wavelength and less penetrating power are produced.
- D. X-rays of longer wavelength and less penetrating power are produced.
- E. None of the above are correct

15. The half-life of an isotope is:

- A. Referred to as LD/50
- B. Its average life passing through a half-value layer
- C. Half of its total life
- D. The time required for the original activity to decrease to one-half
- E. The time required for the source to be reduced to one-half its original size

16. The intensity of X-radiation is usually measured in:

- A. Roentgens
- B. Ergs
- C. R/Hr or mR/Hr
- D. H & D units
- E. Curies

17. If it were necessary to radiograph a 7 inch thick steel product, which of the following radiation sources would most likely be used?

- A. Cobalt-60
- B. 300 KV X-rays
- C. Iridium-192
- D. 600 KV-rays
- E. Radium

18. The curie is a measure of the _____ of the radioactive source.

- A. Size
- B. Activity
- C. Weight
- D. Specific Activity
- E. None of the above

19. When a photon collides with an electron in an atom in the test specimen, and the photon is converted into an electron and a positron, the ionization process involved is called:

- A. Photoelectric effect
- B. Compton effect
- C. Pair production
- D. Photon conversion
- E. Partial absorption

20. Gamma radiation:

- A. Is visible
- B. Ionizes matter
- C. Has an odor
- D. Is hot to the touch
- E. None of the above

21. Ionization refers to:

- A. Slowing down of electrons producing X-radiation
- B. Any action that results in a change in the electrical balance of an atom
- C. Scatter
- D. Photon or bundle of electromagnetic energy

22. The general method of producing X-rays involves the sudden deceleration of high velocity electrons in a solid body called a:

- A. Focus cup
- B. Filament
- C. Target
- D. Cathode

23. The velocity of electrons striking the target in an X-ray tube is a function of:

- A. The atomic number of the cathode material
- B. The atomic number of the filament material
- C. The voltage difference between the cathode and anode
- D. The current flow in the rectifier circuit

24. A source of Iridium-192, whose half-life is 75 days, provides an optimum exposure of a given test object today in a period of twenty minutes. Five months from now, what exposure time would be required for the same radiographic density, under similar exposure conditions?

- A. 10 minutes
- B. 20 minutes
- C. 1 hour and 20 minutes
- D. 6 hours
- E. None of the above

25. The gamma ray intensity at one foot from a one curie source of radioactive Cobalt-60 is nearest:

- A. 15 roentgens per hour
- B. 1,000 roentgens per hour
- C. 1 roentgens per minute
- D. 10 milliroentgens per day
- E. None of the above

26. The unit of measure of X or gamma radiation in air is the:

- A. Millicurie
- B. Gamma
- C. Roentgen
- D. Curie
- E. Milliampere

27. Which of the following is an advantage to the radiographer using a gamma ray source rather than an X-ray machine?
- A. Radiographs generally have greater contrast and greater latitude.
 - B. Greater portability is possible.
 - C. Radiographs generally have greater contrast, but less latitude.
 - D. There is the ability to control radiation energy and intensity.
 - E. The gamma ray sources are easily replaced.
28. When only a portion of a photon's energy is absorbed as it collides with an electron in an atom in the test specimen, the ionization process involved is called:
- A. Photoelectric effect
 - B. Compton effect
 - C. Pair production
 - D. Partial ionization
 - E. Photon transformation
29. The process whereby electrons are liberated from the X-ray tube's filament as current is applied to the filament is called:
- A. Thermionic emission
 - B. Electron emission
 - C. Electron acceleration
 - D. Electron excitation
 - E. None of the above
30. As photons interact with the atomic structure of the specimen, ionization takes place, and as a result of the Compton Effect, secondary photons are generated that are referred to as:
- A. Compton scatter
 - B. Soft radiation
 - C. Side scatter
 - D. Bremsstrahlung
 - E. Back scatter

Chapter 2 Answer Key

1. D
2. C
3. A
4. A
5. D
6. A
7. A
8. A
9. B
10. Ionized matter, harmful, electromagnetic, speed of light, high frequency
11. A
12. E
13. B
14. D
15. D
16. C
17. A
18. B
19. C
20. B
21. B
22. C
23. C
24. C
25. A
26. C
27. B
28. B
29. A
30. A



American Welding Society

CHAPTER 3

Radiographic Film Processing and Viewing

STRUCTURE OF INDUSTRIAL X-RAY FILM

Although the films used for industrial radiography are called X-ray films, they are used for both X-ray and gamma ray radiography. The films used for most industrial radiographic applications are double emulsion films (Figure 3.1). That is, a radiation-sensitive emulsion is coated in layers on both sides of the film's base. Coating both sides of the film's base with the emulsion actually doubles the amount of radiation-sensitive silver halide in the emulsion. A very thin outer protective coating is then applied to both sides of the film.

FILM BASE

Most film bases are made of a flexible polyester, which possesses high tensile strength and dimensional stability and is non-combustible. It must be flexible so it can be formed to the configuration of the test specimen when necessary. It must be able to transmit as much light as possible, and is tinted blue to improve visual contrast.

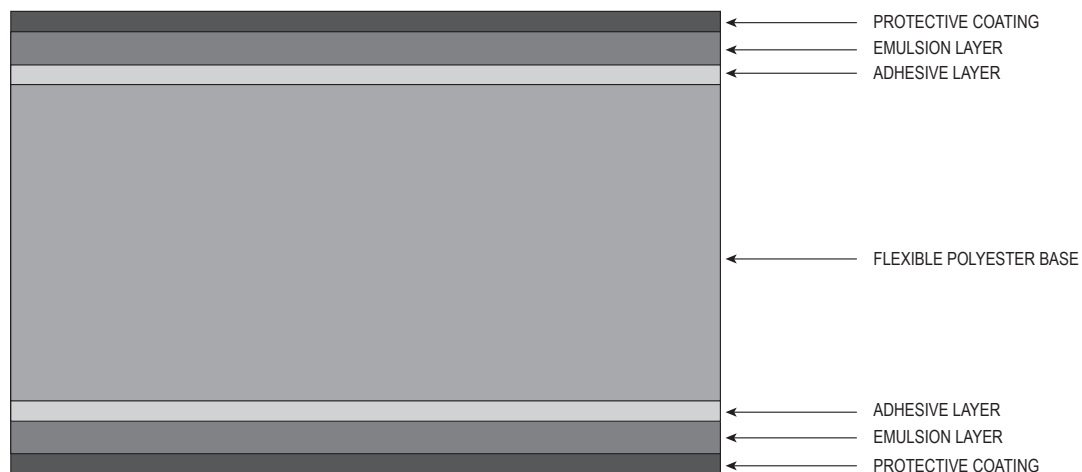


Figure 3.1 Structure of industrial X-ray film

ADHESIVE LAYER

The emulsion will not adhere directly to the smooth surface of the polyester base, so an adhesive is required. The adhesive is applied in a thin coating to the surface of the film base as a substrate layer.

EMULSION

The emulsion is coated on one or both sides of the film base in very thin layers, usually 10μ to 15μ . The emulsion consists of a gelatin material containing photosensitive silver halide crystals, or grains. A latent (invisible) image is formed as electromagnetic radiation interacts with the silver halide crystals. This latent image becomes visible during the processing of the film.

The films that have emulsion on only one side produce greater image resolution and sensitivity. However these single-coated films are much slower films, and therefore require much longer exposure times. The double coated films are used for most industrial radiographic applications. Applying the emulsion to both sides of the films doubles the amount of silver halide crystals; thus, they are faster than the single coated films with the same size silver halide crystals.

PROTECTIVE LAYER

The protective layer is a very thin (1μ) layer of clear gelatin that protects the film emulsion from abrasion and scratches.

TYPES OF FILM

Various types of film are available to satisfy the needs of any radiographic test. Since the selection of a film is dependent upon a number of factors, such as the required quality level, the exposure times, and various economic factors, there are no definite rules regarding

film selection. One rule of thumb is to use the fastest film available that will produce the required radiographic quality level.

Most industrial radiographic films are direct-type films that are sensitive to exposure by ionizing radiation. Direct-type films may be used either with or without lead intensifying screens. The lead screens improve the quality of the radiographic image in two ways: they provide intensifying action by means of electrons that are liberated from the atoms of lead through ionization, and they filter out some of the low energy scatter radiation.

Some films are designed to be used with fluorescent intensifying screens, a type of screen coated with a layer of crystals that fluoresce when exposed to ionizing radiation. Although exposure times can be greatly reduced by the use of fluorescent screens, the radiographs generally will not have as good image definition as the direct-type films, and some codes do not permit the use of fluorescent screens.

When addressing the films to be used, some codes specify that the film types used must be in accordance with ASTM E 94-83, and others reference ASTM E 1815-96. In ASTM E 94-83, films are classified as Type 1, 2, and 3, but ASTM E 94-00 references ASTM E 1815-96 which establishes a detailed procedure to be used by the film manufacturers for the classifications of films used for industrial radiography. This standard establishes four classes that correspond to the former classifications in E 94-83. These four classifications are Special, Class 1, Class 2, and Class 3.

Special Class films are the finest grain films and have maximum contrast and definition, but they are very low speed (i.e. much longer exposure times are required).

Class 1 films are ultrafine grain films with very high contrast and excellent definition, but they have low speed.

Class 2 films are very fine grain films with high contrast and very good definition. Class 2 films are medium speed films.



Agfa	Fuji	Kodak	ASTM E1815	Relative Grain Size	Film Characteristics	Applications
D2	IX25	DR	Special	Extremely Fine	Very high contrast. Ideal when finest possible detail is required. Direct exposure or lead screens	- Electronic Components - Composite Materials - Castings (light metals)
D3	IX50	M	I	Ultra fine	Very high contrast. Excellent sharpness and high detail perceptibility. Direct exposure or lead screens.	- Electronic Components - Composite Materials - Aircraft and Aerospace - Very high quality welds
D4	IX80	MX	I	Extra fine	Suitable for those critical applications requiring detection of small defects. Direct exposure or lead screens.	- Composite materials - Welds (light/medium metals) - Castings - Aircraft and Aerospace - Nuclear Quality
D5		T	I	Very fine	High contrast with wide latitude. Suitable for low to medium Z number metals. Direct exposure or lead screens	- Welds - Castings - Ship building - Aircraft and Aerospace
D7	IX100	AA	II	Fine to Very fine	High contrast and high speed. Suitable for castings and parts with multiple thicknesses. Exposures using lead screens	- Welds (medium/heavy metals) - Castings - Aircraft and Aerospace - Pressure vessels
D8 FD8p	IX150	CX	III	Medium to Fine	Good contrast, very high speed. Suitable for applications where high speed is important. Exposures using lead screens and for even higher speed, fluorometallic or fluorescent screens.	- Concrete - Heavy construction - Castings - In-process screening checks

Table 3.1 Comparison of Agfa, Fuji and Kodak Films

Class 3 films are high speed, fine grain films that exhibit good contrast and definition.

Table 3.1 lists the various Agfa, Fuji, and Kodak films, their classification in accordance with ASTM E 1815, their relative grain size, characteristics and typical applications.

FILM STORAGE

The condition under which film is stored affects the shelf life that may be obtained without increasing the “base fog level.” The basic recommendations for storing X-ray films are:

- Always store film away from radiation sources.
- Storing film in steel cabinets helps shield the film from the effects of scatter or

“sky shine” radiation.

- Always store film in a cool location, because heat will increase the fog level.
- Always store film in a dry location, because excessive moisture will soften the emulsion, thus causing the films to stick together or to stick to the interleaving paper.
- Chemicals should not be stored in the same cabinet as film. Fumes from the chemicals may penetrate the box and affect the films.
- Always store boxes on their edges or ends. Pressure marks may occur if the boxes of film are stored flat and stacked one on top of another.



Figure 3.2 Various X-ray Film Packaging

FILM PACKAGING

BOXED FILMS

Cut film packed in boxes is the most common and least expensive form of packaging. Films are supplied in boxes containing 100 sheets of either interleaved (FW) or non-interleaved (NIF) films. Interleaved films have an individual paper folded over the film that must be removed before the film is exposed; this is referred to as folder wrapped (FW) packaging. The interleaving papers are usually saved and used again to protect the radiographs. As the name implies NIF packaged film does not have the interleaving paper around each film. Cut film comes in a variety of sizes suitable for most radiographic applications.

ENVELOPE PACKED

This is also called “daylight packed” film, and although it is more expensive than boxed film, daylight packed film is very useful for site work. The film is pre-packed, with or without lead screens, into a light tight paper or foil envelope. The only time a darkroom is needed is after exposure, when the film

must be removed from the envelope and processed. The additional cost of this film is often offset in the time saved by not having to manually load film cassettes in the darkroom.



Figure 3.3 Roll Pack

ROLL PACK (READY PACK)

This may be considered as a continuous form of envelope pack. The film and envelope are cut off to the required length, and the ends have to be sealed in the dark. The film is supplied either with or without lead foil screens, in various widths from 70 mm (2.75 in.) to 355 mm (14 in.), and in lengths up to 500 feet. Roll pack was designed mainly for pipe and pressure vessel welds.

DARKROOMS AND FILM PROCESSING

THE DARKROOM

The size, layout and equipment in the darkroom will depend upon whether manual or automatic processing will be used, the volume of films to be processed, and the available space. The darkroom should be located in a central location, adjacent to the reading room and a reasonable distance from the exposure rooms or exposure areas when exposures are made outside of a shielded room (i.e. field operations). When radiography is performed in the field, the darkroom is usually mounted on a pickup truck or a trailer.

Film should be kept in a light-tight cabinet,



which is most often a metal bin used to store and protect the film. One area of the darkroom next to the film bin should be designated as the “dry bench,” where films are loaded in the film holders (cassettes) for exposure and are unloaded for processing. The processing unit should be as far away as possible from the dry bench to protect the film from any water or chemicals that may be located on the surface of the wet side.

FILM PROCESSING

When X-ray film is exposed to ionizing radiation, an invisible image, referred to as the latent image, is formed in the emulsion on the film. Film processing refers to the procedure used to convert this latent image in the emulsion of the film into a visible image. The objective of film processing is to produce a radiograph with a visible image adequate for viewing and to prepare the radiograph for archival storage. Film processing, therefore, is a very important step in the radiographic operation.

Film processing cannot add any details to the latent image; it can, however, take away vital radiographic data. What happens in the darkroom can either make or ruin the best efforts of the radiographer. This is especially true of hand processing, where films can be either over- or under-developed to suit the ideas of the radiographer. When an overexposed radiograph is underdeveloped in order to achieve the required density, its development will most likely be incomplete and will not bring out all the details of the latent image. On the other hand, when an underexposed radiograph is overdeveloped to achieve the required density, the contrast is usually reduced, and some of the density is due to a chemical fog.

Manual processing should always be accomplished using the time-temperature method recommended by the film manufacturers. That is, the time the film is in the developer is

dependent upon the temperature of the developer.

The processing of radiographic film involves four basic steps; development, fix, wash and dry. The processing of the films may be accomplished by manual processing or by use of an automatic film processor.

The applicable code or specification may require that radiographs be maintained in storage for five years or more. In order to ensure that the radiographs will meet this requirement, each step in film processing must be properly controlled.

MANUAL PROCESSING

In the manual processing method, the processing chemicals are placed in tanks as illustrated in Figure 3.4. After being exposed, the films are unloaded from the cassettes and hung on metal hangers, which are then submerged in the processing chemicals. Once submerged, the film hangers should be tapped lightly several times to dislodge any air bubbles clinging to the surface of the film.

DEVELOPER

The primary purpose of the developer is to convert the exposed silver halide crystals forming the latent image into black metallic silver, thus forming a visible image. There are four main constituents of the developer solution.

- ◇ **Developing Agent** which chemically reduces the exposed silver halides into black metallic silver, thus forming the visible image.
- ◇ **Accelerator** which keeps the developer solution alkaline. The more alkaline the solution, the stronger the action of the developing agent.
- ◇ **Restrainer** which prevents development fog by restraining the developing agent from acting on the unexposed silver

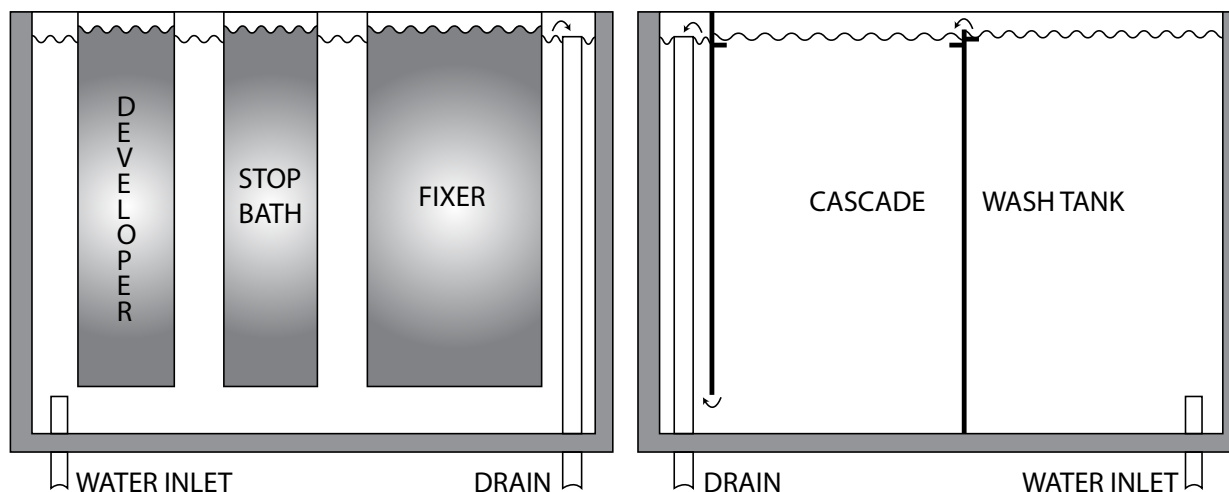


Figure 3.4 Film Processing Diagram

halide crystals.

- ◇ **Preservative** which extends the life of the developer by reducing the oxidation of the developing agent.

Most film manufacturers recommend a 5-minute development time, with the developer at a temperature of 68°F. To provide uniform development of the image, it is necessary to agitate the film while it is in the developer in order to renew developer at the film surface. At the end of the development time, a stop bath solution may be used to stop the developing action and prevent uneven areas of development that may result in streaking on the film. The stop bath is a 3% glacial acetic acid solution that neutralizes the alkaline developer

and thus rapidly stops the developing action. Time in the stop bath should be one to one and a half minutes. Due to space limitations in mobile darkrooms, a stop bath may not be used. In this case, films are thoroughly rinsed in water after developing.

FIXER

After development and stop bath neutralization, the emulsion still contains all the unexposed and undeveloped silver halides. Chemicals in the fixer solution clear these unexposed silver halides from the emulsion, and hardening agents in the fixer tans and toughens the emulsion. Time in the fixer, for complete fixation, should be about 10 minutes.

WASH

When film is removed from the fixer, the emulsion is saturated with the fixer and other compounds which were formed during the fixing process. If not removed adequately, a discoloration and streaking will appear on the film. In order to prevent this, the film is washed in running water for twenty minutes or more. In manual processing, a wetting agent is generally used to reduce the surface



Figure 3.5 Developer Chemicals