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FUJIFILM
TECHNICAL HANDBOOK

The Fundamentals of Industrial Radiography

INTRODUCTION

Nondestructive methods of materials testing has and continues to play a very important role in the remarkable progress made in scientific technology and industry in recent years. Nondestructive methods, assure reliability, quality and performance in industrial products and help to improve manufacturing technology and save costs. These methods have acquired such great importance that they are now indispensable in all manufacturing industries, and as such are winning growing recognition.

Of all nondestructive methods employed for testing in modern industry radiation penetration is most widely use, having the advantages of high reliability, versatility and ability to provide a permanent information record. Radiography finds use in an immense variety of applications, with objects brought under inspection ranging from microminiature electronic circuit devices to aircrafts and ships. An infinite variety of materials including light metals, heavy metals, plastics, wood, and porcelain are also subjected to such nondestructive methods.

To meet the changing needs of modern industry, the FUJIFILM Corporation has always striven to furnish excellent industrial radiographic materials. Research and development in search of new testing materials and automatic processors continues in order to keep abreast of new techniques in radiography. This handbook has been prepared to furnish personnel thus engaged, with information on the fundamentals of industrial radiography. Included are properties of industrial X-ray films and up-to-date processing techniques. The time invested in becoming familiar with the contents of this handbook will result in rationalization and simplification.

NOTICE

In this handbook, ″X-Ray film(s)″ means ″radiographic film(s).″

THE FUNNDAMENTALS OF INDUSTRIAL RADIOGRAPHY

CONTENTS

I. MATERIALS AND EQUIPMENT REQUIRED FOR MAKING RADIOGRAPHS

1. X-RAY AND GAMMA RAY SOURCES

1.1 X-rays and Gamma Rays

X-rays were discovered by W.C. Röntgen. Tradition has it that Röntgen discovered them by chance when he noticed that a screen painted with barium platinocyanide fluoresced when placed in close proximity to a cathode-ray tube.

In his report Röntgen called the newly discovered rays “X-rays” to indicate that their nature was unknown. The rays were also later called Röntgen rays in honor of the distinguished achevement.

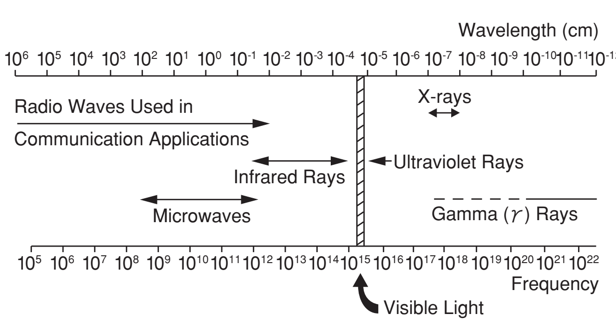
In 1912 M. von Laue and other investigators identified X-rays as electromagnetic waves similar in nature to visible light, though invisible.

X-rays have far greater penetrating power than either visible light or ultraviolet rays. Their nature is such that the shorter the wavelength, the greater the penetrating power.

Radium emits alpha(α), beta(β), and gamma(γ) rays which are penetrating in the same manner as X-rays. In 1898 Marie Curie termed the emanations of this element radioactivity. Besides radium many radioactive elements have since been discovered. At present not only the rays emitted by such radioactive sources but corpuscular beams and cosmic rays emitted in nuclear reactions are also derived from radioactivity.

Of these radioactive sources X-rays and gamma rays are in general practice used in industrial radiography. Gamma rays have greater penetrating power than X-rays. X-rays have a smoothly spread, continuous spectrum, while gamma rays have a discrete spectrum characteristic to the particular radioactive element involved.

Figure 1 Types and Wavelengths of Electromagnetic Radiation



1.2 X-ray Generators

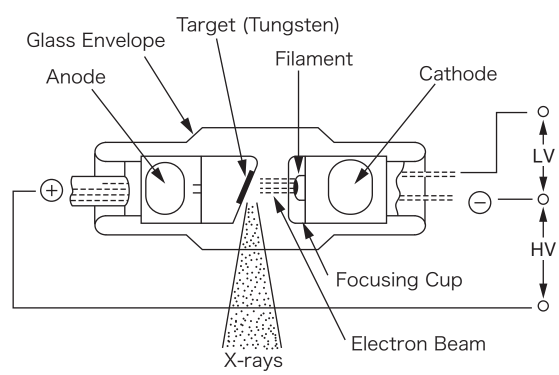
When fast electrons collide with certain materials, their rapid motion is stopped and a small portion of their energy is transformed into X-rays. The vacuum tube that utilizes this phenomenon in the generation of X-rays is called an X-ray tube. A schematic diagram of an X-ray tube is shown in Figure 2.

When high voltage direct current is applied between the cathode and the anode, electrons are emitted by the cathode which flow toward the anode with X-rays being generated when the anode is struck. The voltage applied between the two electrodes is called the X-ray tube voltage, and the surface area of the anode which is struck by electrons is called the target.

As electron emission is facilitated by heating, a filament is incorporated in the cathode that is similar to that in a tungsten filament lamp. A focusing cup is used to direct the stream of electrons so as to obtain a focus on the target. When electrons strike the anode, heat is generated raising the temperature of the anode. Since the target and other parts, are heated to extremely high temperatures, the target is made of high melting point tungsten which also facilitates the generation of X-rays.

The number of electrons emitted from the cathode and, therefore, the dose of X-rays generated off the target of the anode can be adjusted by changing the filament voltage of the X-ray tube. When the X-ray tube voltage is

Figure 2 Schematic Diagram of an X-ray Tube



LV . . . . This terminal is connected to a low-voltage source for filament heating.

HV . . . . This terminal is connected to a high-voltage source for electron emission from the cathode.

changed, the speed at which electrons strike the target changes causing a change in the nature of the X-rays (X-ray energy distribution in relation to spectrum). X-rays which have relatively short wavelengths are called hard X-rays, and those which have relatively long wavelengths soft X-rays.

In an X-ray generator, the line voltage is boosted by a step-up transformer and rectified. As a result, a pulsating voltage is applied to the X-ray tube. In radiography the pulsating voltage that is applied to the X-ray tube is expressed in peak values and the unit symbol kVp is used.

The kilovoltage which is used to cause the emission of electrons in the way described above cannot be increased beyond 400 kVp because of the inadequate dielectric strength of presently available insulators. For faster acceleration of electrons X-ray generators use resonant transformers, static electricity generators, betatrons or linear accelerators.

1.3 Gamma Ray Sources

The typical gamma ray source is composed of a gamma ray-impermeable metal capsule that contains a radioactive element and is provided with a window in the desired position to be opened when radiation is desired. Typical gamma ray sources are such artificially radioactive elements as cobalt 60, iridium 192, cesium 137, and thulium 170.

2. INTENSIFYING SCREENS

X-rays and gamma rays have such great penetrating power that less than 1 percent of the energy is absorbed when striking a film. To utilize the emitted X-rays and gamma rays more fully, recourse is laid to a material which emits less penetrating secondary electrons in the form of fluorescent light, when struck by X-rays or gamma rays. Film is placed between two sheets of such material. This material in sheet form is called an intensifying screen or simply a screen. The intensifying screens are roughly divisible into lead screens, fluorescent screens and fluorometallic screens.

By intensifying the radiation, exposure time can be reduced. The radiation-intensifying effect of these screens, as compared with the exposures made without them, is referred to as the intensification factor, which varies from 2 to 200 depending on the kilovoltage and the type of screen used.

Industrial X-ray films are generally classified according to the type of screen applicable. Films that are used with fluorescent screens are called screen type films, and those which are used with other type screens or without screens are called non-screen type films.

2.1 Lead Screens

Certain materials emit electrons when struck by high-energy X-rays or gamma rays. These electrons are called secondary electrons and photographic film is sensitive not only to light, X-rays and gamma rays but also to secondary electrons. This phenomenon is utilized in the lead screen. Thin lead foil that readily emits electrons when struck by X-rays or gamma rays is bonded to a support so as not to affect penetration. The lead foil is usually 0.03 to 1.0 mm thick and the thickness generally needs to be increased with increasing radiation energy. In X-ray radiography, however, secondary electrons that have the capacity to affect the film are not generated below 100 kVp. Quite to the contary the speed of the film is reduced, as X-rays are absorbed by the lead coating of the screens. In X-ray radiography generally the front lead foil is 0.03 mm thick and the back lead foil 0.03 to 0.1 mm thick. In gamma ray radiography the front and back lead foils used are from 0.1 to 0.3 mm thick. The intensification factor of these lead screens varies from 2 to 3.

2.2 Fluorescent Screens

There are materials which emit light when struck by X-rays. As each fluorescent material, normally called a phosphor, has its own fluorescent light spectral region, an intensification factor of 10 to 200 can be obtained by making an appropriate choice among phosphors relative to the spectral sensitivity of X-ray film. Ordinary fluorescent screens are made by coating a phosphor like calcium tungstate on a support. Fluorescent screens provide for a remarkable reduction in exposure times, but are not used in industrial applications in which minute defects must be detected. This is because they provide poor definition in the resulting radiograph because of the adverse influence of the phosphor particles.

2.3 Fluorometallic Screens

The fluorometallic screen is made by placing lead foil on a support and coating it with a phosphor. It is almost intermediate in nature between the lead screen and the fluorescent screen, but has a shorter life than the lead screen. Fluorometallic screens are suitable for both screen- and nonscreen-type films, the intensification factor ranging from 5 to 30 for the former and from 30 to 150 for the latter.

Figure 3
Structural and Functional Diagram for the Lead Screen

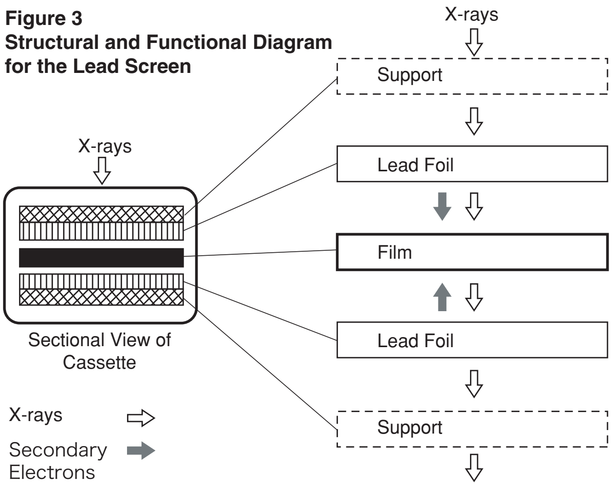


Figure 4
Structural and Functional Diagram for the Fluorescent Screen

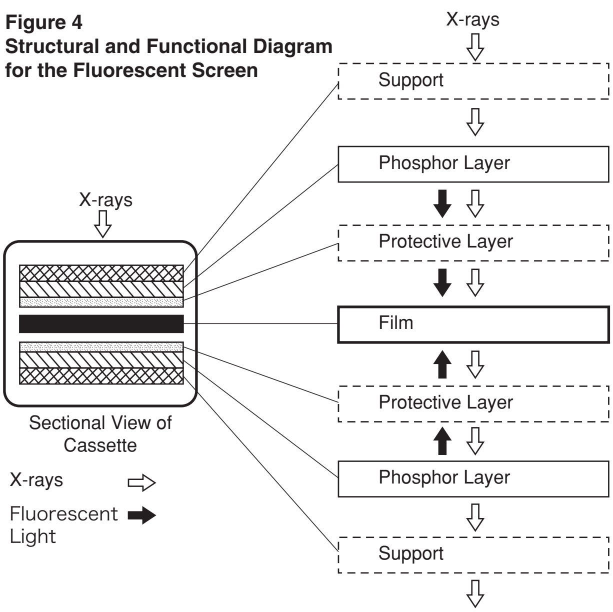
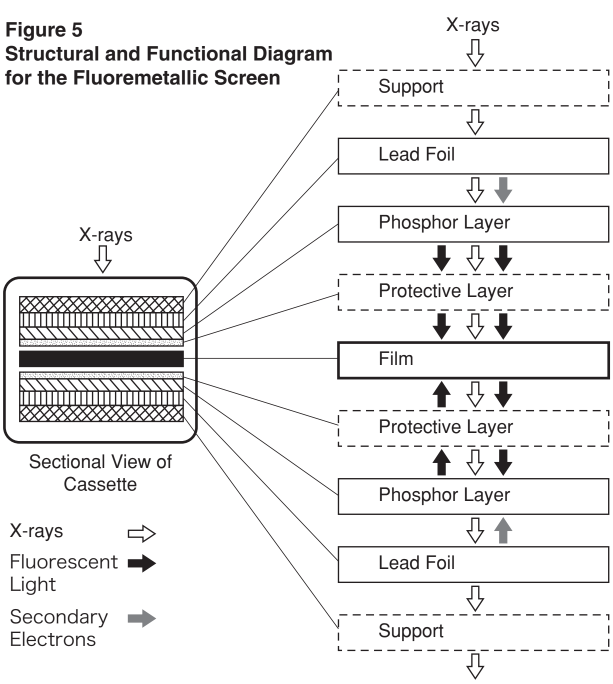


Figure 5
Structural and Functional Diagram for the Fluoremetallic Screen



3. PENETRAMETERS OR IMAGE QUALITY INDICATORS

A test piece which is referred to as a penetrameter or image quality indicator is used to obtain radiographs which better serve the purpose of product testing. Penetrameters are used as an aid in interpreting the radiographs when the internal conditions of a specimen are to be examined in precise detail. Customarily, test exposures are made under varied conditions so as to be able to plot an exposure chart. Specimens are exposed under the conditions derived from the exposure chart. The penetrameter images on the resultant radiographs are checked to evaluate the exposure. The procedures for judgment of penetrameter images are standardized in some countries of the world. Typical penetrameters, wire and plaque types, are shown in Figures 6 and 7.

Figure 6 Typical Penetrameter of the Wire Type (JIS, Japan)

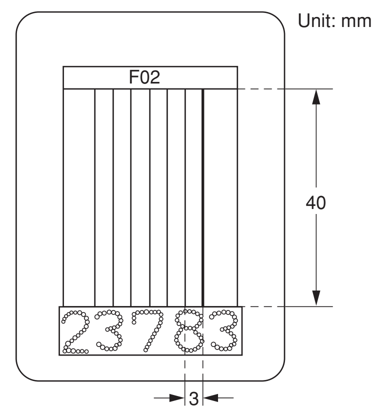
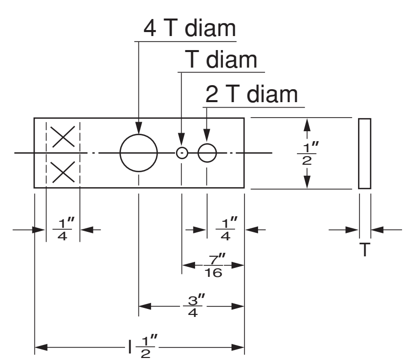


Figure 7 Typical Penetrameter of the Plaque Type (ASME, USA)



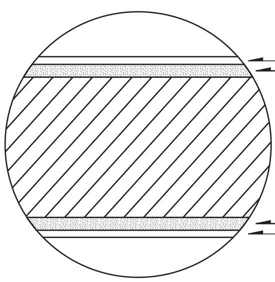
4. INDUSTRIAL X-RAY FILMS

In order to meet the various requirements of industrial radiography Fuji Industrial X-ray Film is available in several types offering distinct advantages such as high speed, high contrast, excellent definition, and fine grain. Radiographs of an excellent quality can be obtained by making an appropriate choice among these films relative to the purposes and kinds of specimens to be radiographed.

4.1 Structure of Industrial X-ray Film

X-ray films for industrial radiography consist of an emulsion and a bluetinted base of polyester 175μ thick. The emulsion is coated on both sides of the base in layers and protected on both sides with thin outer protective layers. The emulsion consists of silver halides as the photosensitive material, additives and gelatin. The silver halides form an image when influenced by X-rays, gamma rays, secondary electrons or fluorescent light. In films for general photography the emulsion is coated only on one side of the base, whereas it is coated on both sides for industrial radiography. The absorption of highly-penetrative X-rays or gamma rays is increased by using two emulsion layers so that the photosensitive silver compound is utilized more effectively for the absorption of radiation and electrons. Furthermore, the two emulsion layers also help to increase the contrast and image density of the radiographs.

Figure 8 Industrial X-ray Film Structure



4.2 Features of the Various Types of Fuji Industrial X-ray Films

X-ray films are generally classified according to the various use purposes involved as shown in Table 1. The types of industrial X-ray films which are available from FUJIFILM Corporation are indicated in the table under the subheading “Industrial X-ray Films”.
The features, speed and contrast of the five types of Fuji Industrial X-ray Films are compared in Table 2.

5. PROCESSING CHEMICALS

Chemicals for the processing of photosensitive materials including X-ray films are dissolved in water for use. Ready-mixed chemicals which result in processing solutions when dissolved in the stipulated volumes of water represent the primary form of use. Refer to III-2 “X-ray Film Processing” and IV-3 “Chemicals for Automatic Processing” for more information on processing chemicals.

5.1 Developer

When photographic film is exposed to light or radioactive rays, an invisible image (called a latent image) is formed in the emulsion layer of the film. The process of converting the latent image to a visible image is called development, and a developer solution is used in this process.

Developer Composition

Chemically, development refers to the reducing action of a chemical. For the exposed film, it is necessary to reduce only the silver compound deposited in the latent image during exposure to metallic silver to form a visible image. The chemical which is chosen to reduce the exposed silver compound to metallic silver is called a developing agent. The developing agent is not used alone but in combination with other ingredients which perform special functions. They include: the accelerator which activates the developing agent; the preservative which reduces the aerial oxidation of the developer; the restrainer which prevents development fog by restraining the action of the developer on the unexposed silver compound; and other additives.

Developer

- Developing Agent
  - [Monol* (equivalent of Metol), hydroquinone, Pyrazon* (equivalent of Phenidone), etc.]
- Other Ingredients
  - Accelerator
    [Sodium carbonate, sodium hydroxide, etc.]
  - Preservative
    [Sodium sulfite, sodium bisulfite, etc.]
  - Restrainer
    [Potassium bromide, etc.]
  - Additives
    [Gelatin hardener, water softener, etc.]

* Trademarks of the FUJIFILM Corporation

Many developers are kept alkaline by the accelerator. The more alkaline the developer or the greater the quantity of accelerator added to the developer, the stronger the action of the developer. The developer for X-ray film contains more ingredients than the developers for conventional black-and-white films, because a larger quantity of silver halide is used in X-ray film.

To save users the trouble of weighing out the individual ingredients of the developer, the FUJIFILM Corporation has made available ready-mixed developers *Hi-Rendol I* (concentrated liquid) which are formulated to give uniform, high-quality radiographs.

5.2 Stop Bath

The silver image becomes too dense to serve the intended purpose unless the action of the developer is stopped at a proper time. If the film is directly transferred from the developer into the fixer, uneven fixation is liable to occur. To stop the action of the developer and prevent uneven fixation, a 1.5 to 3% solution of acetic acid is used as the

Table 1 Classification of X-ray Films

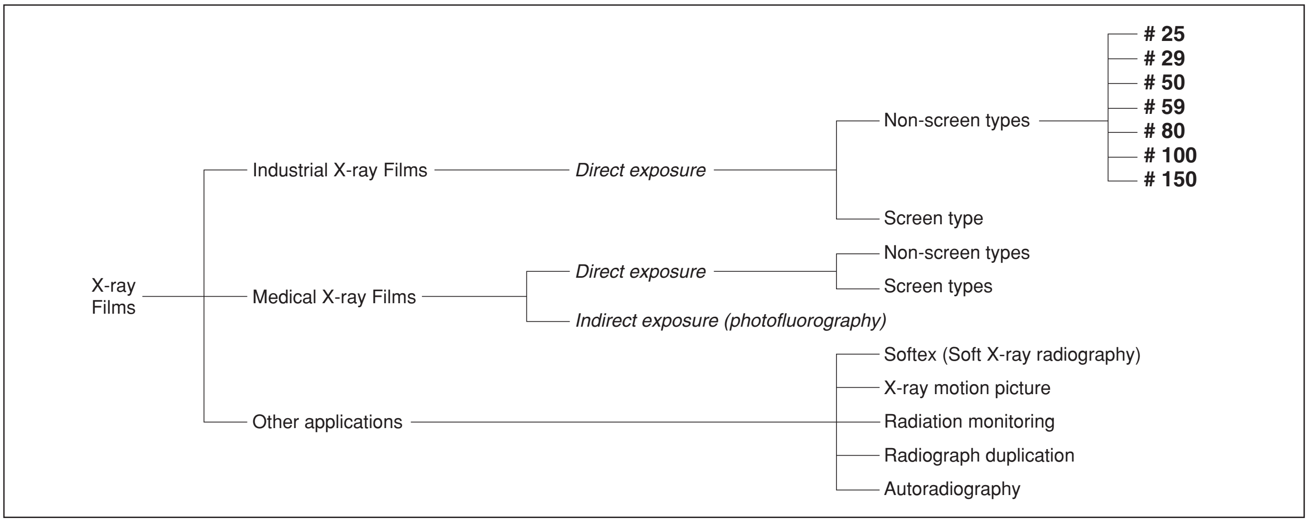


Table 2 Types and Features of Fuji Industrial X-ray Films

Film	Applications and Features	Relative Speed*				Type of Film	
		X-rays 100KV(1)	X-rays 200KV(2)	Ir-192(2)	Co-60(2)	ASTM E1815	EN584-1
#25	Micro-electronic parts, Castings—low to medium atomic number metals. Fuji's finest grain, high contrast ASTM Class Special film having maximum sharpness and discrimination characteristics. It is suitable for new materials, such as carbon fiber reinforced plastics, ceramic products, and micro electronic parts. IX25 is generally used in direct exposure techniques or with lead screens.	20	17	15	10	Special	C1
#50	Electronic parts, Graphite epoxy composites. An ultra-fine grain, high contrast ASTM Class Ⅰ film having excellent sharpness and high discrimination characteristics. It is suitable for use with any low atomic number material where fine image detail is imperative. Its ultra-fine grain makes it useful in high energy, low subject contrast applications where high curie isotopes or high output x-ray machines permit its use. Wide exposure latitude has been demonstrated in high subject contrast applications. IX50 is generally used in direct exposure techniques or with lead screens.	35	30	30	30	Ⅰ	C3
#80	Welds—low to medium atomic number metals, Aircraft construction and maintenance, Graphite epoxy composites. An extremely fine grain, high contrast ASTM Class Ⅰ film suitable for detection of minute defects. It is applicable to the inspection of low atomic number materials with low kilovoltage x-ray sources as well as inspection of higher atomic number materials with high kilovoltage x-ray or gamma ray sources. Wide exposure latitude has been demonstrated in high subject contrast applications. IX80 is generally used in direct exposure techniques or with lead screens.	55	55	55	55	Ⅰ	C4
#100	Welds—medium to higher atomic no. metals, Castings—medium to higher atomic no. metals. A very fine grain, high contrast ASTM Class Ⅱ film suitable for the inspection of light metals with low activity radiation sources and for inspection of thick, higher density specimens with high kilovoltage x-ray or gamma ray sources. Wide exposure latitude has been demonstrated in high contrast subject applications. Although IX100 is generally used in direct exposure techniques or with lead screens, it is suitable for use with fluorescent or fluorometallic screens.	100	100	100	100	Ⅱ	C5
#150	Heavy, multi-thick steel parts, Low curie isotope and low-output x-ray exposures. A high speed, fine grain, high contrast ASTM Class Ⅲ film suitable for inspection of a large variety of specimens with low-to high kilovoltage x-ray and gamma ray sources. It is particularly useful when gamma ray sources of high activity are unavailable or when very thick specimens are to be inspected. It is also useful in x-ray diffraction work. IX150 is used in direct exposure techniques or with lead screens.	200	200	170	170	Ⅲ	C6
#29	Castings and other multi-thickness subjects. An ultra-fine grain, medium-high contrast ASTM Class W-A film suitable to inspect wide ranged thickness subjects such as precision cast parts with X-ray or gamma ray sources. IX29 can be used in direct exposure techniques or with lead screens, or in applications involving fluorometallic screens.	22	22	22	22	W-A	—
#59	Castings and other multi-thickness subjects. An extremely fine grain, medium contrast ASTM Class W-B film suitable to inspect multi-thick, low-atomic number metal, and steel cast parts. IX59 can be used in direct exposure techniques or with lead screens, or in applications involving fluorometallic screens.	45	45	45	45	W-B	—

* Speed as compared to that of type #100 used as a standard 100
(1) without screens (2) with lead screens

stop bath. In radiography a 3% solution of acetic acid is used. If the stop bath is not used, the developer carried over with the film not only increases the exhaustion of the fixer but may become the cause of a lack of processing uniformity or stain formation in the radiograph.

5.3 Fixer

After development and stop bath neutralization the emulsion still contains unreduced silver halide which is not necessary for the image. Such material is detrimental, especially to the radiograph as viewed by transmitted light. The fixer is used to remove the unreduced silver halide.

The commonest fixing baths are solutions of sodium thiosulfate. Ammonium thiosulfate is also used when quick fixation is required. These chemicals possess activity that converts silver halides to soluble compounds. The emulsion which is softened by the developer is hardened by the fixer. Acid hardening baths which stop the action of the developer carried with the film and harden the emulsion are used in all fields of photography, let alone radiography. Almost all fixers in common use are of this acid hardening type.

Fixer Composition

The fixer contains a solvent for silver halide and other ingredients, as shown below.

Fixer

- Silver Halide Solvent
  - [Sodium and ammonium thiosulfates]
- Other Ingredients
  - Preservative
    [Sodium sulfite, etc.]
  - Acid
    [Acetic acid, etc.]
  - Hardener
    [Potassium alum, etc.]
  - Buffer
    [Nabox* (equivalent to Kodalk mild alkali), etc.]

* Trademark of the FUJIFILM Corporation

To save users the trouble of weighing the ingredients of the fixer, the FUJIFILM Corporation has made available ready-mixed fixers *Hi-Renfix I* (concentrated liquid) which are formulated to give good fixation results.

5.4 Wash Accelerator (Quick Washing Agent)

The film removed from the fixing bath retains not only the fixer ingredients but other compounds which were formed in dissoving the silver halides. To remove these, the film is washed in running water for 20 minutes or more. To reduce the washing time the FUJIFILM Corporation has developed a wash accelerator called Fuji QW. This Fuji QW can reduce the washing time to one-third or one-fifth of that required without its use.

5.5 Wetting Agent

When the washed film is dried the processing is completed. After the wash step, water adheres to the film in streaks and drops. If the film is dried in this condition, not only will the drying time be extended but water marks will be left on the radiograph. To reduce drying time and prevent water marks, The FUJIFILM Corporation has developed a wetting agent called *Driwel*.

5.6 Other Processing Chemicals

In addition to the processing chemicals discussed above, certain other chemicals may also be used. When the density of the silver image is too high, a chemical solution called a reducer is used to reduce it. When the density of the silver image is too low, a chemical solution called an intensifier is used to increase it.

5.7 Chemicals for Automatic Processing

Some of the processing chemicals which have been discussed above are also used in automatic processing of X-ray film, but the developer and fixer for use in automatic processing are specially formulated for the following reasons. (For information on the automatic processors refer to Section 6 “Processors” and Chapter IV “AUTOMATIC PROCESSING”.)

A. Developer

In the roller transport type automatic processors (like the Fuji FIP 7000) for industrial X-ray films, processing solutions are used at higher temperatures (about 30°C/86°F) than in manual processing in order to speed things up. Many transport rollers are used to squeegee the film and remove the exhausted solutions from the film surfaces. Developers for use in automatic processors are specially formulated. *Fuji Superdol I*, for instance, is formulated to be suitable for processing at high temperatures and includes special chemicals which adjust the contrast and fog and a hardener which hardens the emulsion in order to give sufficient resistance to forced roller squeegeeing.

B. Fixer

The fixer for use in roller transport type automatic processors is specially formulated (as in the *Fuji Super FI*) so as to produce a greater emulsion-hardening effect than with the fixer used in manual hand processing.
Developer tank transport rollers reduce the amount of developer carry-over to the fixer. This extends the life of the fixer, although the primary function of the rollers is to move the film through the processor.

Notes:

○ Stop Bath
The stop bath is not used in roller transport type automatic processors, because the rollers adequately remove developer solution from the surfaces of the film. This prolongs the life of the fixer to a far greater extent than in manual processing.

- Wash Accelerator
  In roller transport type automatic processors the fixer tank rollers effectively remove fixer from the film surfaces and wash tank rollers provide for continual turnover of fresh water on the film surface so that the necessity of a wash accelerator has not been voiced to date.

- Wetting Agent
  In roller transport type automatic processors the rollers effectively remove the wash water clinging to the surfaces of the film so that the wetting agent is not needed.

6. PHOTOGRAPHIC PROCESSING EQUIPMENT

Photographic processing involves two basic orientations those being manual processing and automatic processing. In the case of manual processing, the processing chemicals are placed in a tray and into this the film is introduced while the tray is tilted back and forth in a repeated pattern to induce the reaction, or the processing chemicals are placed into a tank and the film is suspended with a hanger in the solution so that it can be moved over and over again in the solution. With this kind of manual processing things such as the tray, the solution tank, the hanger and the like are needed by way of equipment. In these types of situations the equipment used comes into direct contact with the chemicals and must therefore be made of materials that are not corroded by this contact. In addition to these items there is the necessity for equipment to control the processing solution temperatures. In this category certain kinds of equipment are placed directly into the processing solutions such as the heater and in other cases the use of a thermostatic bath is central.

Automatic dry-to-dry machine processing is coming into wider acceptance because of the increased stability afforded to the photographic processing itself not to mention the increase in processing speed and abbreviation in processing steps. Most of these processors incorporate mutually or simultaniously driven rollers. The processing steps employed in these types of processors are development, fix, wash and dry being composed of four procedures and in all there are many roller units therein arranged. All of these rollers are driven at the very same speed and thus turn together so that while the film is being transported between them it is also being processed. Normally there are also included in the automatic processor such devices as the temperature control units for the processing solutions, the dryer heater and fan and the automatic solution replenishment devices. For more detailed information see Chapter IV “AUTOMATIC PROCESSING”.

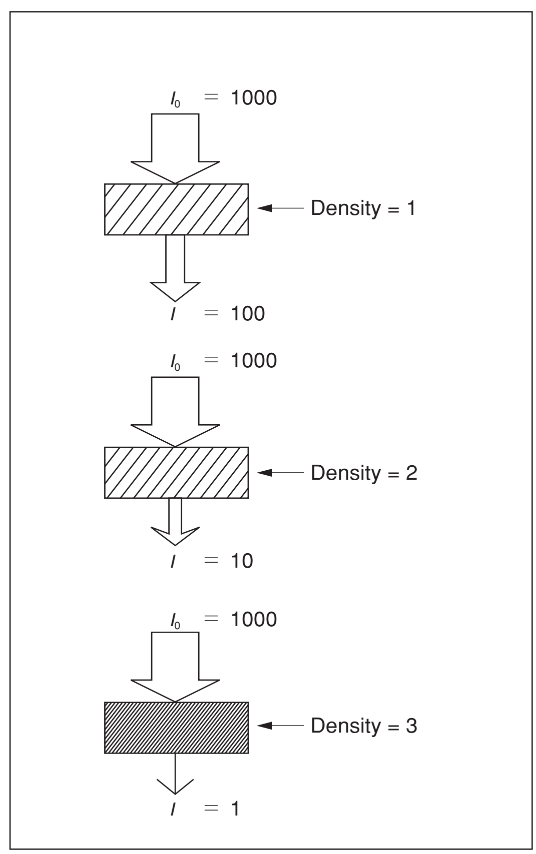
II. PHOTOGRAPHIC CHARACTERISTICS OF X-RAY FILMS

1. PHOTOGRAPHIC DENSITY

The degree of blackening of the photographic image is referred to as photographic density, and there are two kinds of density. One kind is transmission density and the other reflection density. The first kind of density is used to express the density of a photographic image in film. The transmission density of a photographic image is expressed as the logarithm of its opacity. Let the intensity of the light falling on a film surface (incident light) be I_0 and the intensity of the light after it passes through the film be I, and the following equations will hold.

Transparency = I/I_0
Opacity = I_0/I
Density = Log I_0/I

Figure 9 Density



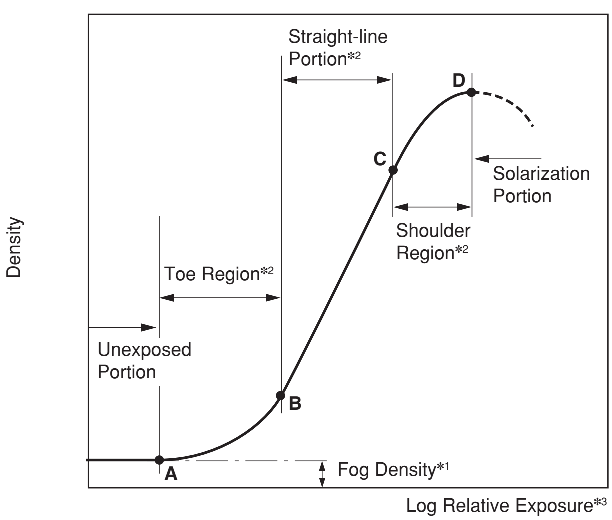
2. THE CHARACTERISTIC CURVE

The properties of X-ray film can be expressed in several ways. The most widely used is the characteristic curve. By the characteristic curve of an X-ray film is meant the curve that results on a graph from plotting the correlation between image density and X-ray or gamma ray exposure that is derived from processing, as illustrated in Fig. 10. This characteristic curve furnishes information on the speed, contrast (average gradient) and fog of X-ray film. As it is difficult to measure the absolute strength of X-rays and gamma rays, relative exposure is determined, and its logarithm expressed as Log Relative Exposure is plotted along the horizontal axis of the graph against the density which is laid off along the vertical axis at intervals equal to those on the horizontal axis. The shape of the characteristic curve and its position on the graph differs from one type of film or radiation source to the other. Further, variations in the curve are seen with varying processing conditions and relative to the presence or absence of intensifying screens.

Customarily, the characteristic curve is divided into five sections, as shown in Figure 10: (1) the unexposed position; (2) the toe; (3) the straight-line portion; (4) the shoulder; and (5) the solarization portion.

Note: The term sensitometry refers to the science of establishing accurate numerical values for exposure-density relationships and the determination of film speed, contrast, fog and other parameters as derived from the characteristic curve.

Figure 10 Designation of the Five Sections of the Characteristic Curve



**1 Fog Density*
The fog density may or may not include the base density. In many instances it is not indicated whether base fog is included or not.
**2 Toe, Straight-line and Shoulder Portions*
These designations indicated fairly well-defined portions of the characteristic curve, but do not have such distinct points as B and C in Figure 10.
**3 The logarithm of the relative exposure when the film is exposed to X-rays or gamma rays.*

Unexposed Portion:
A density which is just noticeable appears in the unexposed areas of processed film and this density is called fog.

Toe Region:
Underexposed films generally have a density in the range indicated by this section.

Straight-line Portion:
Properly exposed films generally have a density in the range indicated mainly by the straight-line section and toe. Contrast is most closely related to the straight-line section.

Shoulder Region:
Overexposed film generally has a density in the range indicated mainly by the shoulder and straight-line portion.

Solarization Portion:
The density may even fall again upon increasing exposure above that indicated by the shoulder. This portion is not included in exposures used for the formation of photographic images.

Figure 11 Characteristic Curve of a Non-screen Type Film

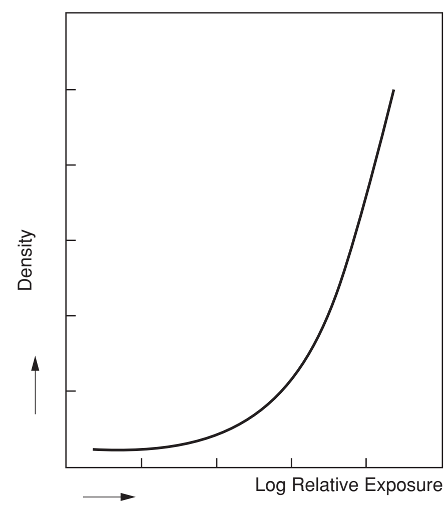
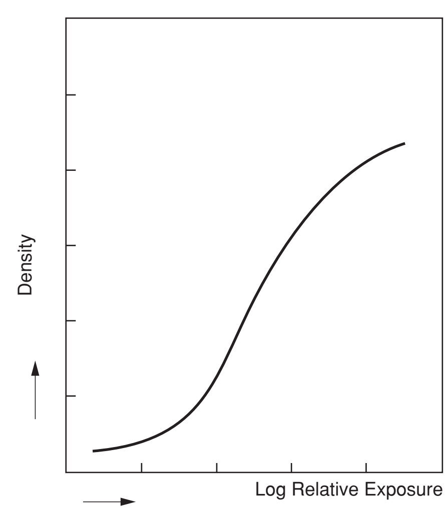


Figure 12 Characteristic Curve of a Screen Type Film



3. SPEED

The term speed used in radiography refers to the sensitivity of X-ray film to X-rays or gamma rays. The speed of a photographic material is usually expressed by the reciprocal (see note) of the exposure as determined from its characteristic curve as this has obtained a certain density after development under given conditions. As the relative exposure is used in plotting the characteristic curve of X-ray film, the speed which is derived from it is also indicated by a relative value and is therefore called the relative speed.

Note: The speed scale is so arranged that the speed decreases with increasing exposure and increases with decreasing exposure. The speed is therefore expressed by the reciprocal of the exposure for ease of understanding.

Figure 13 shows characteristic curves for four types of film A, B, C and D which were exposed to X-rays and processed under given conditions. This graph is plotted by laying off the density along the vertical axis and the relative exposure along the horizontal axis at equal intervals starting from 0.0 at the left on the horizontal axis. By locating the density point of 2.0 above fog-plus-base density on the characteristic curve a straight line can be drawn from this point down to the horizontal line. With the relative exposures for the four types of film, the relative antilogarithms can be calculated. By allowing one type of film, for instance A, to become the reference film with a speed of 100, the relative speeds of the other types of films can be obtained using the reference speed of 100 and the inverse ratios of the antilogarithms read from the horizontal axis. The relative speeds of the four types of film thus determined are shown in Table 3.

Table 3 Relative Speeds

Type of Film	A	B	C	D
Relative Speed	100	209	48	26

4. AVERAGE GRADIENT

The contrast for industrial X-ray film is expressed by the average gradient ($\overline{G}$)*. The certain range of all densities which form a photographic image significantly influences its contrast. The slope of a straight line joining the points of the highest and lowest densities of this range on the characteristic curve is defined as the average gradient.

* $\overline{G}$ is read Gee bar.

The density range (ΔD) for industrial X-ray films is defined as follows:

$$\Delta D = (\text{fog-plus-base density} + 3.5) - (\text{fog-plus-base density} + 1.5)$$

The density range on a characteristic curve is shown in Fig. 15.

Figure 13 Characteristic Curves for Four Types of Film

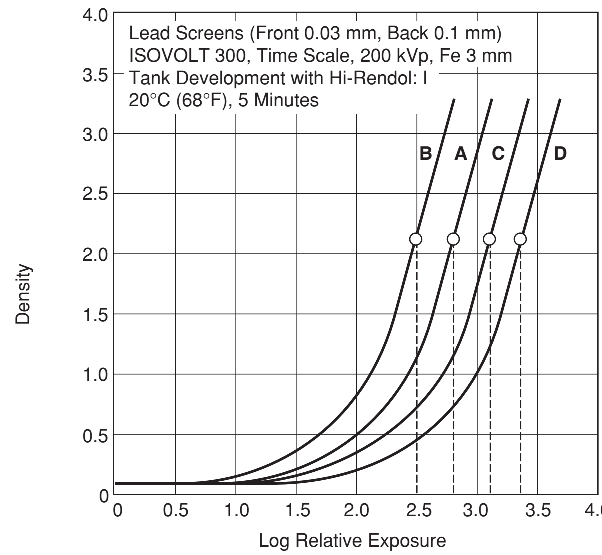
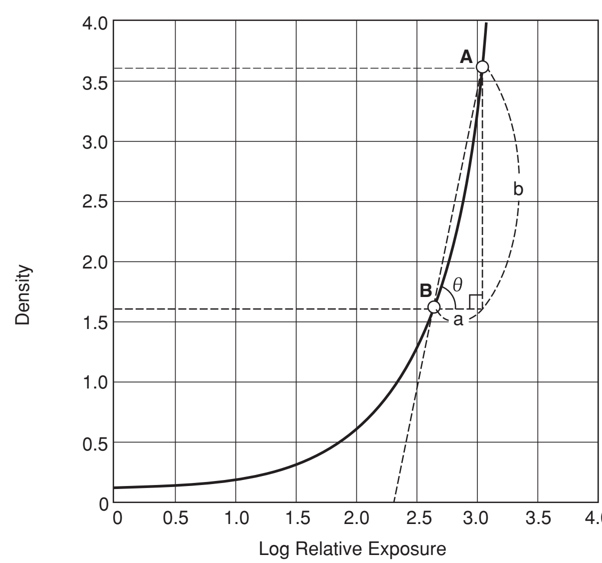


Figure 14 Average Gradient



Point A = Fog-plus-base density + 3.5
Point B = Fog-plus-base density + 1.5
ΔD = b

The slope ($\tan\theta = \frac{b}{a}$) of the straight line joining points A and B in relation to the horizontal axis is called the average gradient ($\overline{G}$).

5. FOG

Film may have a slight density without being exposed to visible light, X-rays or gamma rays. This density is produced when the silver halide in the emulsion of the film is in part reduced and is called fog. As fog that exceeds a certain limit produces a detrimental effect on the photographic image, it must be inhibited as far as possible.

Fog has many causes which include film storage conditions, composition of the developer, development conditions, and handling conditions. Undersirable densities which are caused by light and pressure are also called fog. Unwanted density caused by excessive exposure to a safelight (even though a light color which does not affect the sensitive material is used within reasonable limits of time as the safelight) is called safelight fog. The unwanted density which is produced when a high pressure is exerted on the film is called pressure fog. All these kinds of fog which are produced by undesired external factors adversely affect the photographic image and must therefore always be prevented.

6. DEFINITION OR SHARPNESS

Definition or sharpness are the photographic terms which are used to indicate the distinctness of the boundary between differing densities and the clearness of the fine detail in a image.

Recently use has been made of spatial frequency characteristic for photographic images to express sharpness. The concept of spatial frequency was derived from electronic measurement systems. In electronics technology the characteristics of a speaker, for instance, is expressed by plotting what we call a frequency response curve. The amplitide ratio of input to output (called a response) is calculated for each varying sound frequency, with the frequency being laid off along the horizontal axis and the response along the vertical axis. A frequency response curve as shown in Figure 16 can thus be obtained.

If the reproduction of the low-pitched sounds is poor, the response in the low frequency range is small, and if the high-pitched sounds are not faithfully reproduced, the response in the high frequency range is small. This frequency response curve is very useful when evaluating the quality of a reproduced sound. In photography, on the other hand, the frequency response curve is drawn by plotting the number of black-and-white lines per mm (which is called spatial frequency after the analogy of audio frequency) against the input-output ratio, this is, the response of the reproduced image to the visible light or radioactive rays as an input (Figure 16). This plot is referred to in photography as the response function or modulation transfer function.

7. GRAININESS

The photographic image produced after development consists of silver particles a few microns in diameter which are irregularly distributed. That is why raidographs usually have a grainy appearance, when viewed by the naked eye. This appearance is called graininess. It is clumps of developed silver grains rather than single grains which impart the grainy appearance. Graininess is a subjective impression, and its objective aspect is referred to as granularity. The former is subjectively determined by the naked eye, using either constant sample illumination or constant field brightness. The method of determination is selected relative to the purpose for which the film is intended, but the constant sample illumination method is best suited to X-ray films.

On the other hand granularity is physical and refers to the structure of the light sensitive emulsion which is objectively determined by physical methods. Granularity is superior in reproducibility and objectivity to graininess as a scientific measure of the variation in the distribution of silver deposits. Granularity is determined through the use of Selwyn's method fo Fourier analysis.

Figure 15 Sound Frequency Response Characteristics

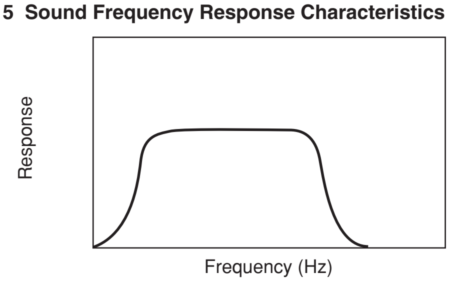


Figure 16 Photographic Frequency Response Characteristics

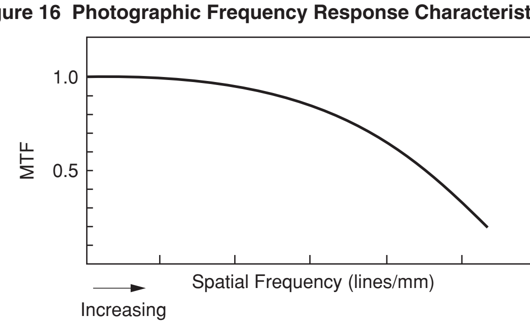
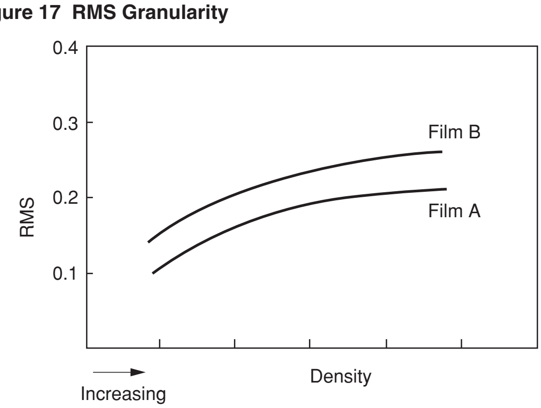


Figure 17 RMS Granularity



Selwyn granularity G is expressed as a product of the square root of an area a of a microdensitometer measuring aperture and standard deviation σD for a given average density D. Selwyn granularity: G = $\sigma D\sqrt{a}$ However, this formula does not result in constant value for G when the area of certain individual silver grains is larger than the area a of the measuring aperture. Today granularity is expressed by the value of σD alone more often than by Selwyn's constant, and is referred to as RMS granularity (root-mean-square granularity). The smaller the RMS value, the better the granularity. In Figure 17, for instance, film A has better granularity than film B.

III. MAKING OF RADIOGRAPHS

1. RADIOGRAPHIC EXPOSURE

1.1 Precautionary Concerns in Set-up

It is important to comply with the standards established for industrial X-ray films and consider the effect of geometric factors (e.g., specimen-to-film distance) on the image quality when determining the arrangement of the X-ray or gamma-radiation source, the cassette, the specimen and the penetrameter. It is also necessary to make an appropriate prior choice of exposure method according to the material and the shape or the portion of the specimen to be examined. For instance, when examining a welded pipe, the most appropriate choice should be made from among the single radiography method, the stereoscopic radiography method and the double-exposure (parallax) method.

1.2 Determination of Exposure Conditions

In industrial radiography it is necessary to determine the exposure so as to meet such requirements as essential image density and penetrameter determined definition.

Table 4 Factors Affecting the Exposure

DECREASING	⬅	EXPOSURE TIME	➡	INCREASING
Thin	←	Thickness of Specimen	→	Thick
Small	←	Specific Gravity of Specimen	→	Great
High	←	Kilovoltage	→	Low
Short	←	Focus-to-Film Distance	→	Long
High	←	Intensification Factor of Screen	→	Low
Large	←	X-ray Tube Current	→	Small

NOTE: Determine the exposure conditions for specimens of varying thickness with the aid of an exposure chart.

The X-ray equipment needs a warm-up period as prescribed by the manufacturer, and in the case of a gamma radiation source it is necessary to ascertain its Ci value. When X-rays are used, a radiograph of high definition can be obtained by using low kilovoltage with long exposure time. An exposure chart is generally used as a guide for determining exposure conditions (e.g., kilovoltage, X-ray tube current, and exposure time). Ordinary exposure charts are plotted by laying off the thickness of the specimen along the horizontal axis and the exposure (mA·min. or mA·sec.) or kilovoltage (kVp) along the vertical axis of a graph.

However, it is recommended that appropriate exposure charts be plotted according to exposure conditions for each case, as the results of exposures vary with the variable characteristics of the X-ray source, the focus-to-film distance, the specimen material and desired image density. In the case shown in Figure 18 the kilovoltage is determined from the thickness of the specimen and the exposure is made under conditions (mA·min.) determined by the kilovoltage. In the case shown in Figure 19 the intensifying screen is chosen relative to the thickness of the specimen and the exposure made at kilovoltages suited to the type of screen chosen.

Figure 18 An Exposure Chart Example
Milliamperage and Peak Kilovoltage

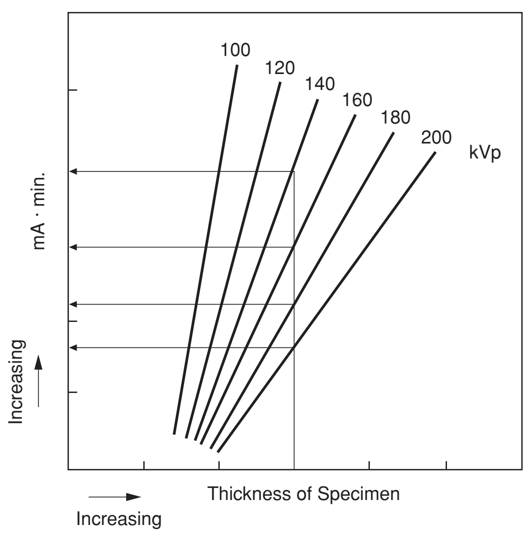
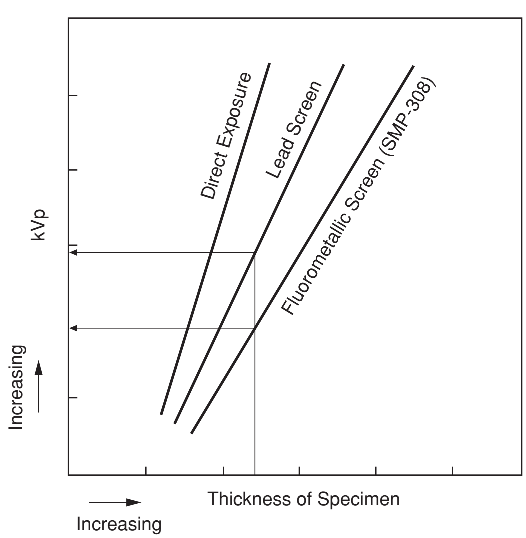


Figure 19 An Exposure Chart Example
Peak Kilovoltage and Intensifying Screen



1.3 Care in Film Handling

When removing the X-ray film from the interleaved paper folder, no more pressure than necessary should be exerted on the interleaving paper, or scratches and static electricity marks may be left on the X-ray film. Also leave the interleaving paper on the X-ray film when it is placed on the work bench before exposure, as it protects the film from dirt, iron powder, moisture, chemicals and other undersirable matter.

Good, uniform contact between the screens and the film is very important. If they are in poor contact, the image definition sharpness will be adversely affected. Particular care should be used to obtain good contact between the screens and the film, when the casettes are of the flexible type. When removing the film from a vacuum cassette, take out the film with the screens and remove the film by opening the screens so as to avoid friction between screens and film.

2. X-RAY FILM PROCESSING

The image produced on X-ray film through exposure to X-rays, gamma rays, or light is invisible before processing, but a visible image appears when immersed in a special processing solution. This processing step is called development. Development is stopped when an image of desired density and contrast is obtained. The film is then immersed into a stop bath which brings to a halt the action of the developer. After the stop bath the film is immersed into a fixing bath which dissolves the unchanged portions of the sensitive silver salts. The film thus treated has a permanent image. The steps in making a permanent image after exposure are collectively called processing.

This section will deal with manual processing, and automatic processing will be discussed later in Chapter IV.

2.1 Development

Development exerts a significant effect on the photographic quality of radiographs. For best results the various conditions of development must be kept constant. Factors of particular importance will be discussed here.

Developer Temperature and Development Time

The image density and contrast of a radiograph are remarkably influenced by the development temperature and time. It is necessary to keep the developer at a specified temperature (usually 20°C/68°F for manual processing) and carry out development during a specified time. When the temperature of the developer is higher than normal, much the same results are had as obtained by extending the development time, and vice versa. In either case, however, it is most desirable that the temperature of the developer be kept within a range of from 18 to 23°C (64.4 to 73.4°F). As the development time may vary with each brand of developer, be sure to observe the instructions given by the manufacturer. The time and temperature specifications for Fuji *Hi rendol I* developer are 5 minutes and 20°C (68°F).

Time Related Development Properties

The photographic properties of X-ray film change when the development time is changed while maintaining other conditions of development, such as temperature and agitation, constant. Speed and contrast increase to a certain extent with increasing development time but contrast may fall due to fog or other causes and the graininess may become coarser when a certain development time limit is exceeded. Even when the development time needs to be extended so as to increase speed and contrast, a maximum limit of 8 minutes should not be exceeded at a developer temperature of 20°C (68°F). Figure 21 is an expression of the relationships between development time and photographic properties for X-ray film.

Developer Agitation

During development, the developer solution or the hanger loaded with exposed film is agitated at frequent intervals in order to keep the emulsion in contact with a fresh solution at all times, thus accomplishing even development. If the film is not agitated during development, the solution in contact with high-density areas of the film will be locally exhausted so that development of those areas stops, while the solution in contact with low-density areas is exhaust to a lesser extent so that development proceeds. As a result, such a radiograph will show low contrast. The locally exhausted solution affects the rate and evenness of development by moving from one area of the film to the other during development. Thorough and even agitation of the film during development is very important. When tray processing is used, care should be taken to assure that radiographs do not cling to one another, and the tray should be rocked to provide continual mixing and redistribution of the solution.

Figure 20 Developer Temperature-Time Curve

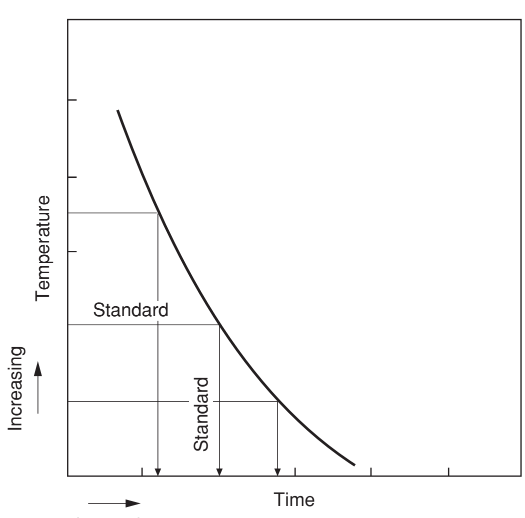
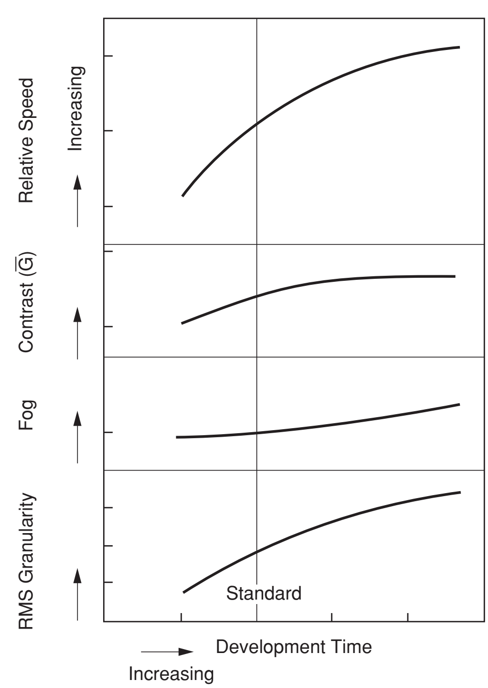


Figure 21 Development Time Related Photographic Properties of X-ray Film



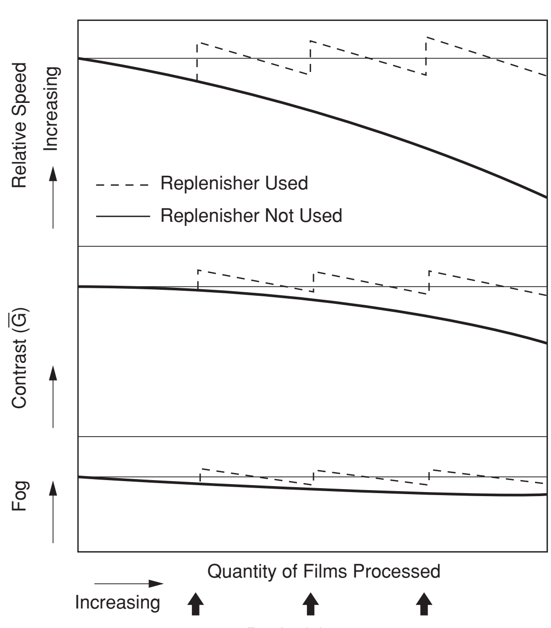
Developer Exhaustion and Replenishment

If the water volume is not accurately measured in the preparation of developer solutions, the resulting properties will be divergent from the original specifications and fog may result. Accurate measurement of water is therefore important. However, it should be remembered that the development capacity of even an accurately prepared developer solution decreases, as it is used. It is necessary to check the developer solution for exhaustion by maintaining records of the sizes and quantities of X-ray films processed and the number of days the developer has been used.

To obtain uniform radiographic results over a period of time, it is necessary to check the use condition of the developer solution and add developer replenisher in proportion to the quantity of film processed or at regular intervals. Figure 22 shows a graph in which the effects of the developer replenisher on the photographic properties of X-ray films are demonstrated. The rate of replenishment varies with the size and quantity of films and the average density. The developing power of the developer decreases with increasing density or film size, and vice versa. The relative areas of various size films as determined by assigning the value 1 to the reference size 25.4 x 30.5 cm (10 x 12 in.), are shown below.

Film Size	Relative Area
35.6 x 43.2 cm (14 x 17 in.)	2
25.4 x 30.5 cm (10 x 12 in.)	1
11.4 x 43.2 cm (4-1/2 x 17 in.)	0.6
8.5 x 30.5 cm (3-1/3 x 12 in.)	0.3

Figure 22 Effects of the Developer Replenisher on the Properties of X-ray Films



The replenisher should be added in small quantities and at frequent intervals in order to reduce variations in developer solution activity for the sake of uniform radiographic results.

2.2 Stop Bath

As the function of the stop bath is to nullify the action of the developer through the action of the acetic acid, care should be taken to assure that the action of the developer is nullified over the entire surface of the film. Care should also be used to prevent a rapid change in the extent of swelling in the emulsion layer. To meet these requirements the stop bath should be maintained at a constant temperature close to that of the developer solution. If the temperature of the developing solution is 20°C (68°F), the temperature of the stop bath should be maintained within a range of from 15 to 20°C (59 to 68°F).

For about 15 seconds after the film passes into the stop bath, it must be continuously agitated so as to prevent development unevenness. Care should be used to assure that films do not cling to one another, and films should be immersed in the stop bath for about 30 seconds.

The stop bath is checked for exhaustion with a pH meter. When the pH of the stop bath exceeds 6.0, its neutralizing power has decreased to such an extent that it no longer is able to perform its proper function. Make it a rule to replace the stop bath when its pH value is close to the critical level of 5.5. If a stop bath cannot be prepared for one reason or another, a fresh running water rinse may be used in place of an acetic acid stop bath.

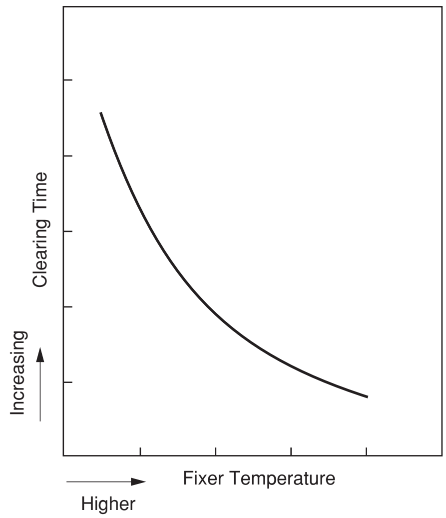
2.3 Fixing

A permanent image cannot be retained in the exposed and developed X-ray film unless it is treated with the fixer. As the fixing conditions greatly influence the degree of radiographic permanency, sufficient care should be exercised to fulfil the required fixing conditions in maintaining rigid control over the fixer.

Fixer Temperature and Fixing Time

The fixer temperature does not influence the fixing speed to such a remarkable extent that the developer temperature affects development time, but generally speaking fixing time decreases with an increase in fixer temperature. The relationship between the fixer temperature and fixing time is shown in Figure 23. It is necessary to adjust the fixer temperature to within close range of the developer temperature to avoid temperature differential related detrimental effects on the emulsion.

Figure 23 Fixer Temperature-Time Curve



Fixing requires twice the time that elapses from the moment the film is immersed in the fixer solution to the time the milky emulsion becomes completely transparent. If the fixing time is inadequate, the film retains some insoluble salts (complex silver thiosulfate compounds). If they are allowed to remain, they will slowly decompose and attack the image, causing it to discolor and fade. Even if the fixing time is to exceed the clearing time by twice, the quality of the processed radiographs will not be adversely affected. It is therefore recommended that longer fixing times be used even an the risk of exceeding by twice the film clearing time so as to provide a safeguard against discoloration and image fading. On the other hand, however, if the film is allowed to remain in the fixer solution for too long a time, the density of the image will decrease and the film will acquire a brown color. Granularity may also be impaired depending on the circumstances. Care should be exercised to insure that films are not left in the fixing bath for too long a time or forgotten.

Fixer Agitation

When the film is first transferred from the stop bath into the fixing bath, it should be agitated continuously for 10 seconds and then thereafter occasional agitation is to be employed. Care should be exercised to insure that films do not cling to one another. If the stop bath is unavoidably skipped (the skipping of the stop bath should be avoided by all means as such practice will become the cause of uneven development), and the film is directly transferred from the developer solution into the fixing bath, or if the film is rinsed after development and transferred into the fixing bath, it must be agitated vigorously in the fixer for about 30 seconds. If agitation is not vigorous enough, uneven fixation may result and even dichroic fog and stains may occur when the fixer solution is exhausted.

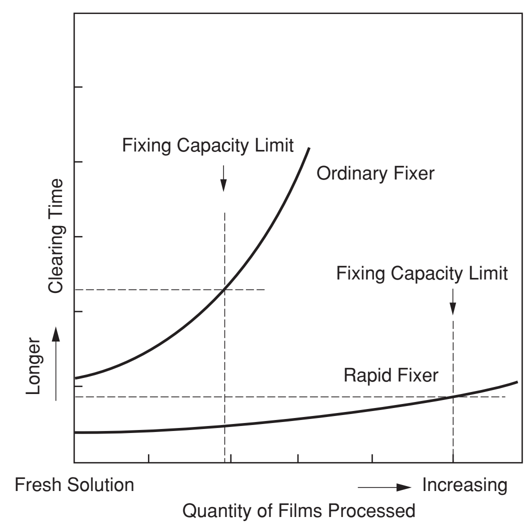
Fixing Capacity

Customarily, the fixer solution is not replenished and as such used until exhausted beyond use. As it is used, its fixing capacity decreases to a point at which the time required for the film to clear is increased by twice the time required with fresh fixer solution. When this critical state has been reached, the fixer solution should be replaced. If this limit is exceeded, proper fixation will not be accomplished even if the film is allowed to remain in the fixer solution longer than twice the clearing time. Further such practice will result in image discoloration or fading.

When a solution of ammonium thiosulfate is used as a fast-acting fixer not only is the film cleared in a shorter time but twice the fixing capacity of ordinary fixer solutions is made available. The fixing capacity limit is apt to be exceeded more easily with fast-acting fixer solutions because the time to clear is short, even when twice the fixing time needed by a fresh solution is required.

However, as the use of exhausted fixers will cause discoloration or image fading, such should be avoided. Clearing times and fixing capacities for ordinary and fast-acting fixers are compared in Figure 24.

Figure 24 Clearing Time and Fixing Capacity of Fixers



As film after film carries the processing solution of the preceding step into the fixing bath, the fixer solution is exhausted in time. The amount of processing solution carried on the film exerts a significant effect on the strength of the fixer solution. The smaller the carry-over the less the fixer solution will be degraded. If film is to be drained thoroughly, it must be held out of solution for a long time and such exposure to air brings with it the risk of discoloration. Films wet with any of the processing solutions should not be allowed to remain in contact with the air for longer than 10 seconds.

When films are transferred time and again directly from the developer solution into the fixing bath, or rinsed and transferred into the fixing bath without using the stop bath, the hardening capacity of the fixer solution decreases rapidly so that films are easily scratched or longer than normal drying times are required after washing. Furthermore, under these conditions development may proceed even in the fixing bath, leading to dichroic fog* and uneven fixation.
In such cases it is necessary to replace the fixer solution even before complete exhaustion has taken place.

* Dichroic Fog

This kind of fog is liable to result from the presence of traces of developer in the fixing bath. When viewed by transmitted light, film with dichroic fog has yellowish to brownish stains. The stains are of a bluish, greenish or yellowish metallic luster when viewed by reflected light.

2.4 Washing

Thorough washing is necessary to remove the processing solutions and complex silver salts (complex silver thiosulfate compounds). As is often the case, sufficient care may not be exercised after fixing. If such salts are allowed to remain after washing, they will gradually decompose and attack the image, causing it to discolor of fade.

Wash Water Flow Rate and Temperature

The faster the flow of the water in contact with the emulsion the faster the undesired compounds are removed and the shorter the washing time becomes. The wash water temperature should preferably be slightly lower than the fixer temperature so as to avoid adverse conditions in the emulsion. In practice, however, considerable capacity is required to maintain adequate control of wash water temperature. Ideally, the developer temperature should be 20°C (68°F) and the wash water temperature 15 to 17°C (59.0 to 62.6°F), but water temperature varies greatly with the season. (Variations of as much as from 30°C/86°F during the summer season to below 10°C/59°F during the winter season are not uncommon.) If such variations are present, there is no alternative but to make slight changes in the stop bath and fixer temperatures in favor of the wash water temperature, as shown by way of example in Table 5.

Washing Time

The processed X-ray film should be washed in running water at 20°C (68°F) for 50 minutes or more. When the wash accelerator *Fuji QW* is used, the X-ray film should be washed according to the following procedure.

After fixing the X-ray film is rinsed in running water for 30 seconds. It is then immersed in the QW solution for 1 to 2 minutes and then washed in running water for 5 minutes.

Figure 25 Washing Time and Residual Thiosulfate

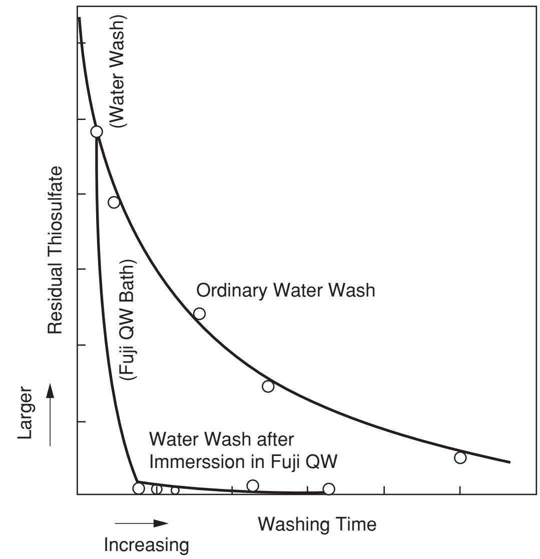


Figure 26 shows the washing times and quantities of residual thiosulfate after washing with and without the QW process sequence.

2.5 Drying

Film should be dried immediately after washing. Water streaks and drops adhere to film surfaces and if they are not removed prior to drying, the areas lying underneath will dry more slowly than the surrounding areas changing thus the density of the silver image and resulting in spots. Such uneven drying can be prevented by gently wiping the film with a sponge or immersing it in a solution of the Fuji *Driwel* wetting agent. (Dilute *Driwel* in water at a ratio of 1:200 respectively and immerse the washed film in it for about 30 seconds prior to drying.) The forced air dryer should have a filter over the air inlet fan position with the unit providing 45 to 50°C (104 to 122°F) hot air movement over the film.

2.6 Standard Processing Procedure and Temperature Adjustment of Processing Solutions

Processing Steps (Temperature at 20°C/68°F)

Development:	Hi-Rendol Ⅰ or Rendol	5 minutes
Stop Bath:	3% acetic acid solution	30 seconds
Fixing:	Hi-Renfix Ⅰ or Renfix	5 to 10 minutes
Preliminary Wash:	Running water	30 seconds
Wash Acceleration:	Fuji QW solution	1 to 2 minutes
Water Wash:	Running water	5 minutes
Drying:	Natural or forced air	

Care should be taken to assure that the temperature does not differ by more than ±5°C (±9°F) from one solution to the other. If it differs to an extent greater than this differential swelling of the emulsion will result from area to area leading to reticulation.

Table 5 Examples of Temperature Adjustments for Processing Solutions

	DEVEL-OPER	STOP BATH	FIXER	WASH WATER
Summer	20°C (68°F)	22 to 25°C (71.6 to 77.0°F)	25 to 28°C (77.0 to 82.4°F)	30°C (86°F)
Winter	20°C (68°F)	18 to 15°C (64.4 to 59.0°F)	16 to 13°C (60.5 to 55.4°F)	10°C (50°F)

Table 6 Factors Determining Radiographic Contrast

	HIGH	←	CONTRAST	→	LOW
Film contrast (Factors related to film and processing)	High	←	Density level	→	Low
	Vigorous	←	Developer agitation	→	Gentle
	Slight	←	Developer exhaustion	→	Advanced
	Appropriate	←	Development time	→	Too long or short
	Appropriate	←	Developer temperature	→	Too high or low
	High	←	Developer contrast	→	Low
	High	←	Contrast inherent to film	→	Low
Subject contrast (Factors related to specimen and exposure)	Used	←	Lead screens	→	Not used
	Used	←	Filter	→	Not used
	Limited	←	Radiation Scattering	→	Profuse
	Low	←	Kilovoltage	→	High
	Great	←	Difference in specimen thicknesses	→	Small

Table 7 Factors Determining Radiographic Sharpness

	HIGH	←	SHARPNESS	→	LOW
Factors related to development, fluorescent screen and film	High	←	Film contrast	→	Low
	Fine	←	Film graininess	→	Coarse
	Appropriate	←	Degree of development	→	Excessive
	Fine	←	Fluorescent screen graininess	→	Coarse
Factors related to exposure	None	←	Motion of X-ray equipment	→	Great
	None	←	Motion of subject	→	Great
	Good	←	Contact between screens and film	→	Poor
	Short	←	Subject-to-film distance	→	Long
	Long	←	Focus-to-film distance	→	Short
	Small	←	Focus area	→	Large
	Thin	←	Specimen thickness	→	Thick
	Low	←	Kilovoltage	→	High

3. FACTORS AFFECTING THE USEFULNESS OF RADIOGRAPHS

The factors which determine the usefulness of radiographs include contrast, sharpness and density.

3.1 Contrast

The term contrast refers to the difference between the maximum and the minimum densities of a radiograph. It may also refer to the degree of density change in the image. The contrast of a radiograph is expressed through a combination of film contrast and subject contrast.

3.2 Sharpness

The factors which affect image sharpness in a radiograph are listed in Table 7. Silver grains become coarser with increasing kilovoltage, and this tendency is more marked when fluorescent screens are used. These factors should be taken into due consideration when making radiographs to be used for examination of specimens in fine detail.

3.3 Density

It is necessary to maintain at fixed levels the densities of radiographs for use in nondestructive testing. The definition in non-screen type films increases with increasing density.

3.4 Image Magnification and Distortion

The image in a radiograph may be magnified and distorted depending on geometrical arrangements relative to the positions of the radiation source, the specimen and the film. The causes of image magnification and distortion are listed in Table 8.

4. FILM STORAGE AND THE DARKROOM

4.1 Storage and Care of X-ray Films

Unexposed X-ray films are readily and adversely affected by chemicals, heat, moisture, mechanical pressure, visible light and radiations such as X-rays and gamma rays requiring that utmost care must be taken in the storage and handling of such films and in the selection of storage locations.

a. Industrial X-ray films are generally stored near the radiation source in readiness to serve the purposes for which they are intended but in this regard are more sensitive to radioactive rays than other types of sensitive materials. What matters most in the storage of unexposed industrial X-ray films is the provision for adequate protection against radiation. Lead-Lined containers should be used when unexposed films and loaded cassettes are to be kept in the X-ray room. The darkroom must be separated from the X-ray or radiation source room by a partition wall which can completely shut out radiation.

b. As industrial X-ray films are quite sensitive to heat and moisture, a cool, dry place should be chosen for storage. Storage temperatures should remain at around 10 to 15°C (50 to 59°F). Fuji Industrial X-ray Films are enclosed in interleaving paper folders and sealed in light tight, moisture proof envelopes so that they are relatively safe from moisture before being removed from these envelopes. However, once the film is removed from the envelope, the emulsion will absorb moisture until it attains equilibrium with the moisture content of the surrounding air. Relative humidity for industrial X-ray film handling should be from 60 to 70%. On the other hand, excessive dryness is not suitable to the storage of industrial X-ray films, because in such locations films may become charged with static electricity resulting in marks on the radiographs. X-ray films removed from their envelopes should be wrapped in air tight vinyl sheeting and kept under refrigeration, to be removed several hours before use and allowed to stand until equilibrium with room temperature is attained. If such films do not have the same temperature as that of the ambient room air, moisture may condense on the film surfaces.

c. Industrial X-ray films may develop fog, when exposed to polished metal surfaces, painted surfaces, thinner, hydrogen peroxide, coal gas, hydrogen sulfide, ammonia gas, mercury vapor, formalin, engine exhaust gases, acetylene and terpene. Provision should be made to prevent the occurrence of this kind of fog which is referred to as a false photographic effect.

d. The emulsion layer is scratched when strongly rubbed, so that black streaks appear in the processed radiograph. A shadow looking like a crescent, generally called a kink mark, is seen in the radiograph when the film is folded. Generally, the crease made in a film before exposure seems to have a lower density than the surrounding area, while the crease made after exposure seems to have a higher density than the surrounding area. Mechanical pressure also influences the film likewise. Marks resulting from contact with fingers that are contaminated with processing chemicals can be avoided by wearing thin, soft cotton gloves. The use of gloves made of synthetic fibers or gloves of synthetic fibers blended with cotton should be avoided, as they may cause static marks to appear on the radiographs.

Table 8 Image Magnification and Distortion

SLIGHT	⬅	MAGNIFICATION AND DISTORTION	➡	GREAT
Short	←	Specimen-to-film distance	→	Long
Long	←	Focus-to-film distance	→	Short
Thin	←	Specimen thickness	→	Thick
Right angle	←	Angle between X-ray beam center and plane of specimen and film	→	Oblique

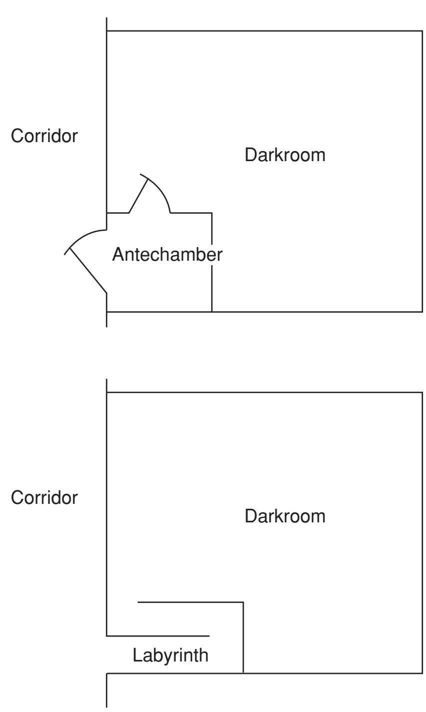
4.2 Darkroom Design

The space for the darkroom should be determined by the volume of work to be done there, but generally speaking, high efficiency of operation can be achieved when it is spacious enough to allow two to three persons to work in it together at the same time. The darkroom must be completely protected against Radiations. The inner surfaces of the darkroom should be treated with a material which is resistant to processing chemicals and can be washed with water in the area where water is used. The walls should be painted in a light color which best reflects light from the safelight. The walls of the labyrinth should be painted matt-black to absorb any reflected light, and a white line should be painted at about eye-level to assist entry and exit. A ventilator is also necessary to keep the air moving from the dry side to the wet side of the room and out. The darkroom should have an antechamber or a labyrinth that makes an efficient light trap.
Preferably there should be a film loading darkroom and a processing darkroom. If film loading and unloading and processing are to be carried out in the same darkroom, the wet area should be in a position opposite to that of the dry area. The following precautions should be observed, when the darkroom area is large enough for a loading darkroom and a processing darkroom.

Loading Darkroom (Dry Area)

The loading darkroom is to be provided with film containers, cassette and film holder storage, and a loading bench. The loading darkroom should always be kept clean, and free of water and chemicals.

Figure 26 Light Traps for the Darkroom



Processing Darkroom (Wet Area)

The processing tanks, washing tanks, hanger racks and work benches should be arranged to facilitate film processing. Forced ventilation is necessary since the air is readily contaminated in a hot and humid processing darkroom. An air-conditioner may also be necessary to keep the air dry.

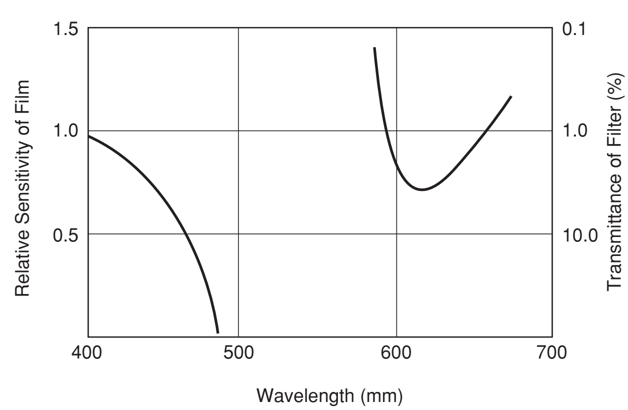
4.3 Safelight

Light having spectral qualities that are outside the region in which sensitive materials are affected is to be used for safelight illumination. The Fuji Safelight Filter SLG 8U (colored dark reddish orange) is recommended as such for use in the darkroom. The relationship between the spectral sensitivity of Fuji Industrial X-ray Film and the spectral transmission factors for the Fuji Filter SLG 8U safelight is shown in Figure 27. Industrial X-ray films should be handled at a distance of at least 1 meter from the Fuji Filter SLG 8U safelight in which a 100-volt, 15- or 20-watt lamp is incorporated. The safelight may be turned on under normal conditions for 10 to 15 minutes without any detrimental effect on X-ray film.

The safety of the safelight in use can be tested in the following way. A sheet of industrial X-ray film is placed in its normal handling position and covered with a sheet of black paper. The black paper is moved at 5-minute intervals to expose the X-ray film to the safelight in step fashion, and an unexposed portion is left. When the test X-ray film is processed under standard conditions, it can be discerned from the processed film how long the safelight should be allowed to remain on without causing fog in the film.

Safelight filters should be checked for discoloration or fading every six months and replaced, if necessary, because they may discolor or fade in time due to the influence of heat from the incandescent lamp, humidity and chemicals.

Figure 27 Spectral Characteristics of Fuji Industrial X-ray Film and Safelight Filter SLG 8U



4.4 Processing Tanks

The processing solutions are either alkaline or acidic so that the processing tanks must be alkali or acid resistant. Suitable materials include stainless steel, plastics and enamelware.

Plastics have such low thermal conductivity that plastic containers are suitable for keeping processing solutions warm that have already been warmed, but the contents of such containers cannot be rapidly heated or cooled from the outside. Stainless steel which provides adequate protection against corrosion and provides easy temperature control is in wide use.

Relative volumes essential to the processing tanks:

Developer tank	2
Fixer tank	3 to 4
Wash tank	5 to 6
Stop bath tank	1

IV. AUTOMATIC PROCESSING

Over the past few years there has been an increasing demand from industry for a time saving simplification of nondestructive testing methods. Equipment which has been developed to solve the various problems associated with the complexity of industrial X-ray film processing, is rapidly coming into widespread use. Dry-to-dry processing which requires one hour when carried out manually can be accomplished in about 5 minutes, when recourse is had to an automatic processor. Furthermore, the automatic processor can reduce variations in radiographic quality. However, the processor alone cannot produce such remarkable effects unless combined with suitable film and processing chemicals. This chapter will deal with the fundamentals of automatic processing with reference to the processor, film and chemicals.

1. THE AUTOMATIC PROCESSOR

Until relatively recently X-ray films have been for the most part processed manually, but hand processing has gradually been replaced by automatic processing. Automatic processing requires careful control of the processor and processing solutions, but is more advantageous than hand processing in many ways. Besides the elimination of variations in the quality of radiographs, the automatic processor does not occupy much space, it helps to keep the darkroom clean, can be easily installed and effects significant savings in processing time and labor. A system of rollers is generally employed as a transport system in the automatic processor. As an example a sectional view of the *Fuji FIP 7000* Processor is shown in Figure 28.

1.1 Rapid Access to Finished Radiographs through Automatic Processing

The following methods are effectively employed to gain rapid access to finished radiographs through automatic processing.

Raising Processing Solution Temperatures

The chemical reactions are facilitated through the application of relatively high temperatures to the processing solutions.

Reinforcing Chemical Solution Supply to Film Surfaces

A fine spray or processing solution jet is applied continuously to the film surfaces as solutions are forced to circulate in the processing tanks to keep them well mixed and maintain them in agitated contact with the film surfaces. Such methods facilitate chemical reactions between the emulsion and the processing chemicals.

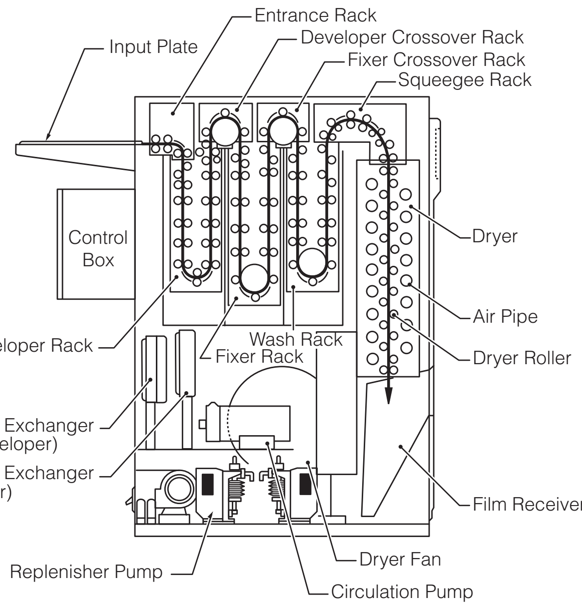
Increasing Chemical and Film Interaction through Transport Roller Pressure

The film is brought into direct contact with the transport rollers so that the rollers not only squeegee the film but force processing solutions against the film surfaces, thus facilitating chemical reactions.

1.2 Industrial X-ray Film Processor

By way of example the standard processing conditions established for the Fuji FIP 7000 Processor are shown in Table 11. The quality of the results obtained with a Fuji FIP 7000 processor (with Superdol I) may differ to some extent from that obtained in tank processing (with Fuji Hi-Rendol I) depending on the type of sensitive material used.

Figure 28 Sectional View of Fuji FIP 7000 Processor



Fuji Industrial X-ray Film Processor FIP 7000

Table 9 Conditions for Manual and Automatic Processing

	DEVELOPMENT	STOP BATH	FIXING	WASHING	FINISHING BATH	DRYING	TOTAL
MANUAL PROCESSING	20°C/68°F	20°C/68°F	20°C/68°F	20°C/68°F	20°C/68°F	40°C/104°F	
	5min.	30sec.	5min.	50min.	30sec.	30min.	91min.
FUJI FIP 7000 PROCESSOR	30°C/86°F	—	31°C/88°F	31°C/88°F	—	About 45°C/113°F	
	1min. 00sec.	—	1min. 05sec.	1min. 00sec.	—	50sec.	5min. 45sec.
	23°C/73°F	—	31°C/88°F	Max 35°C/95°F	—	About 45°C/113°F	
	2min.	—	2min. 10sec.	2min.	—	1min. 40sec.	11min. 30sec.

1.3 Care in Automatic Processing

In automatic processing it is indispensable that certain processing conditions be fulfilled and kept constant as indicated in Table 10. Processing control should be rigidly practiced by making periodic measurements so as to avoid variations in solution temperatures, replenishment rates and wash water flow rates. The essential checks which should be made in the operation of the Fuji FIP 7000 Processor are indicated in Table 11.

Table 10 Processing Conditions Established for the Fuji FIP 7000 Processor

FACTOR		PROCESSING CONDITION (5 min. Processing)	PROCESSING CONDITION (11 min. Processing)
DEVELOPMENT	Developer Developer temperature Development time Developer tank capacity Replenishment rate	Superdol I (25 ml per liter of Superdol SI starter) 30°C/86°F, 1 min., 30 lit. 65 ml/4 sheets of 8.5 x 30.5 cm film	 23°C/73°F 2 min.
FIXING	Fixer Fixer temperature Fixing time Fixer tank capacity Replenishment rate	Super FI 31°C/88°F 1 min. 05 sec., 24 lit. 200 ml/4 sheets of 8.5 x 30.5 cm film	 2 min. 10 sec.
WASHING	Water flow rate Wash water temperature Washing time	10 lit/min 31°C/88°F 1 min.,	 2 min.
DRYING	Drying temperature Drying time	About 45°C/113°F 50 sec.	 1 min. 40 sec.
PROCESSING SPEED	Film transport speed Processing capacity	60 cm/min. 400 sheets/hr (8.5 x 30.5 cm film)	30 cm/min. 200 sheets/hr (8.5 x 30.5 cm film)

Table 11 Check List for the Fuji FIP 7000 Processor

	CHECK	PROCEDURE	ADJUSTMENT
PROCESSING SOLUTIONS	Measure replenishment rates for developer and fixer.	○ Remove hook from filling hole and sample replenisher.	Adjust replenishment rate by adjusting knob.
	Measure solution temperatures of developer, fixer, wash and dry.	○ Read thermometers and measure temperatures of tank solutions.	Adjust thermostats and change pre-set temperatures, as necessary.
X-RAY FILM	Check photographic properties of finished radiographs.	○ Expose test pieces through step wedges or make production exposures to ascertain photographic properties of finished radiographs.	Adjust volume of starter, developer temperature and developer replenishment rate.
	Check other processing results	○ Check fixing power of fixer (by measuring fixing speed). ○ Check drying condition. ○ Check emulsion.	Adjust fixer temperature and replenishment rate. Adjust wash water flow rate. Adjust drying temperature.

2. REQUISITES TO X-RAY FILMS FOR AUTOMATIC PROCESSING

Industrial X-ray films designed for automatic processing must meet the following requirements.

Increased Adaptability to Rapid Processing

In spite of satisfactory development the image in a radiograph may discolor and fade with time, if fixing, washing and/or drying are not adequate. Films which are processed in automatic processors, must therefore meet special requirements that conventional industrial X-ray films need not comply with. For instance, the emulsion layer must be thinner and the emulsion must react with processing chemicals more rapidly.

Increased Strength of the Emulsion Layer

Rapid processing will serve no purpose if resulting quality is inferior to that of hand processing. When solution temperatures are increased, softening and swelling of the emulsion layer is also increased subjecting the film to much severer physical conditions and roller pressure. The emulsion layer of industrial X-ray film for automatic processing must therefore be strong enough to withstand such severe processing conditions.

Adoption of a Polyester Base

More than ten years has elapsed since inflammable cellulose nitrate as a film base was replaced with noninflammable cellulose acetate. Later polyester base materials have come into commercial use following upon progress in the plastics industry and the advent of automatic processors. Polyester base materials are advantageous in several ways. Such materials provide for flatness and great strength. Little expansion and contraction take place and the material is not hygroscopic. These salient features of polyester as the film base are indispensable to rapid processing in automatic processors.

3. CHEMICALS FOR AUTOMATIC PROCESSING

To some extent the composition of chemicals formulated for use in automatic processors differs from that of chemicals used for hand processing. The most pronounced difference is that the former contain chemicals which protect the film against mechanical pressure and roller stains. The chemicals for use in the automatic processor are supplied in concentrated liquid form, and a starter system is adopted for ease of use. The major requirements which automatic processor chemicals must meet will be discussed in this section.

Rapid Reaction and Activity Recovery

In automatic processing both development and fixing are to be completed respectively within the brief span of about 1 minute and 30 seconds. Processing solutions must provide for quick recovery of working strength, when replenished at rates proportionate to the quantity of film processed, so as to give constant results.

Suitability for High Temperature Processing

As processing solutions are maintained at high temperatures, they must be formulated so that performance will not be adversely affected by high temperatures.

Extended Performance Maintenance

Processing solutions are generally used in automatic processors over a long period of time without being replaced. Throughout this period the processing solutions must show consistent performance, without soiling the tanks, racks and films.

3.1 Control of Processing Solutions

It is indeed rare when chemicals manufactured under exactly the same conditions possess precisely the same properties. In actuality, there are differences that exist to a greater of lesser extent. Accordingly it is unavoidable that X-ray films processed in automatic processors show some degree of variation in quality. Radiographic quality is affected by the following factors, making it necessary to minimuze such variations in the control of processing solutions.

3.2 Developer Control

As in hand processing the activity level of the developer solution used in automatic processing is kept constant by the addition of replenisher. The degree of exhaustion of the active components may differ from case to case depending on the type of processor, the average density of the radiographs, and the water quality even if the quantities of films processed remain constant.

Even when the same replenishment rates are continued in use in different laboratories, there is little wonder that the activity of the developer solutions differ over time from one situation to the other. The developer solution should therefore be controlled in a manner suited to the specific conditions of the particular laboratory. The developer solution is controlled in several ways, but in radiography the sensitometric and densitometric methods are in general use as control procedures of high practical value.

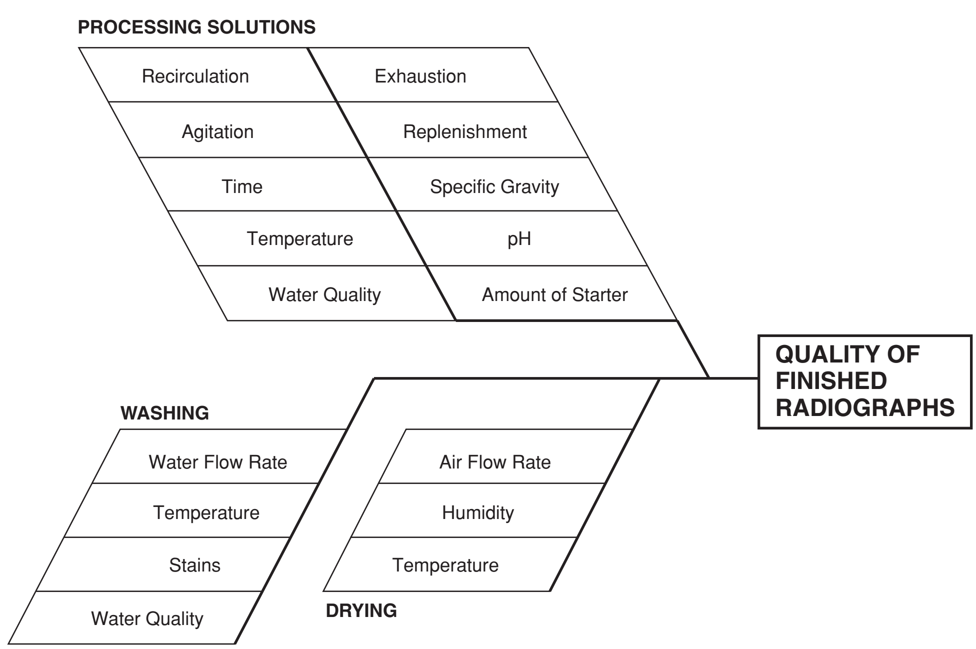
Sensitometric Method
This method provides the highest control accuracy. A control strip which is exposed to visible light or X-rays in step fashion is developed under predetermined conditions and a characteristic curve is derived from this control strip. The characteristic values (of speed, contrast and fog) obtained from the characteristic curve are graphically represented. If characteristics of the control strip deviate from normal, corrective action is taken to bring the developer solution into control. In practice, the characteristics obtained from the fresh developer are used as the standard and a control strip is processed after processing a certain number of films or at the beginning of each work shift (at the time that processing conditions are stabilized following processor preparation). The results obtained with control strips are compared with the standard thus derived so as to bring the developer solution into control if there are seen shifts from the standard.

Densitometric Method
The densitometric method also uses control strips as in sensitometric control. The density of a specific step of relatively high density is used to plot a control chart. The control film is processed at the same specified times as indicated for the sensitometric control method.

3.3 Fixer Control

An exhausted fixer solution will produce adverse effects relative to the permanency of radiographs. It is necessary to check the fixer solution for exhaustion at regular intervals and replenish it with fresh solution as required for constant chemical activity.

Figure 29 Quality of Finished Radiographs



Fixer Control Through Measurement of Residuel Silver Salts

The silver salts remainning in the film after fixing are measured in order to determine the activity of the fixer solution. A transparent unexposed fully processed film is cutoff and its density is measured. This piece is then tested under conditions indicated below. If silver salts remain, they are converted into silver sulfide and the test picece turns brown in color. The densities of the treated and non-treated films are measured through a blue filter. If the difference of the density obtained from this transparent film before testing in the test solution is 0.03 or less as subtracted from the value obtained after testing, the fixer solution can be considered to have adequate activity.

TEST PROCESSING

Test Solution Formula

Water	100 ml
Sodium sulfide	2 grams

The test solution should be kept in a stoppered bottle and should not be used when stored longer than one month. Dilute with water at a ratio of 1:9 when used, and do not keep the diluted test solution longer than one week.

Test Steps

Test Solution 3 min.
↓
Washing 10 min.
↓
Drying

3.4 Wash Water Control

The flow rate, temperature and quality of the wash water are very important factors affecting the quality of radiographs in automatic processing where washing is completed in a short period of time. A water flow rate of 10 liters or more per minute is required, although this varies with the type of processor. Generally, the higher the water flow rate, the higher the washing efficiency, while the washing time can be reduced by using a high wash water temperature.

The effectiveness of the washing process is determined by measuring the amount of silver thiosulfate remaining in the film after washing, employing one of the following four methods. In general practice, however, the silver nitrate method is employed in preference to the others because of higher accuracy and greater testing ease.

○ Potassium Permanganate Method
○ Iodine Method
○ Silver Nitrate Method
○ Mercuric Bichloride Method

Silver Nitrate Method

A transparent end of an unexposed but fully processed film is cut off and its density is measured. This piece is then tested under the following conditions and its density is measured through a blue densitometer filter. If subtraction of the density value obtained before immersion in the test solution from the value obtained after such immersion results in a value of 0.05 or less, the washing process can be considered adequately effective.

TEST PROCESSING

Test Solution Formulas

A Solution	Water	700 ml
	Glacial acetic acid	30 ml
	Silver nitrate	10 grams
	Water to make	1000 ml
B Solution	Water	700 ml
	Sodium chloride	50 grams
	Water to make	1000 ml
C Solution	Water	700 ml
	Sodium thiosulfate	50 grams
	Sodium sulfite	19 grams
	Water to make	1000 ml

Test Steps

Solution A 4 min.
↓
Solution B 4 min.
↓
Solution C 4 min.
↓
Washing 5~10 min.
↓
Drying

* The density of the film tested in the single solution procedure should be measured quickly, as its color will darken under the influence of white light.

V. EXAMPLES OF PROBLEMATIC FILM HANDLING

FAULTS ASSOCIATED WITH STORAGE

Light Fog

Phenomenon

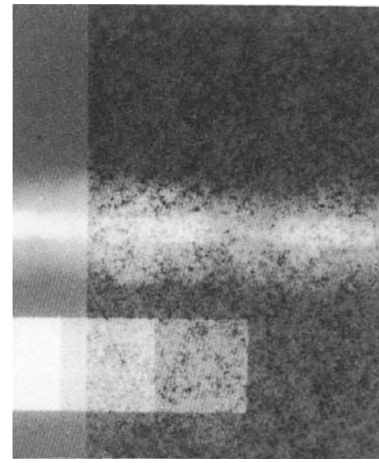
The radiograph is fogged in the same pattern as that of the interleaving paper texture.

Probable Cause

The film has been exposed to light while yet covered with interleaving paper.

Corrective Action

1. Check the darkroom for light leaks.
2. Check the X-ray film storage box for light leaks.
3. Before turning on the normal room lights make it a rule to insure that no film is on the work bench.
4. Be sure to seal the X-ray film case after use.



Light Fog

Radiation Fog

Phenomenon

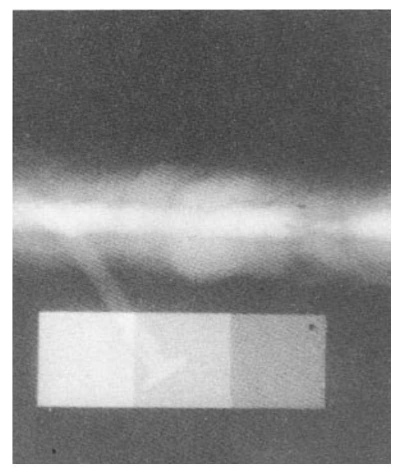
The shadow of an unexpected object or the lead foil as embeded in the X-ray film case, appears in the radiograph.

Probable Cause

The film has been exposed to X-rays or gamma rays during storage.

Corrective Action

Keep X-ray films in a lead foil coated X-ray film storage box and store it in a place which is free of radiation.



Radiation Fog

FAULTS ASSOCIATED WITH THE SAFELIGHT

Safelight Fog

Phenomenon

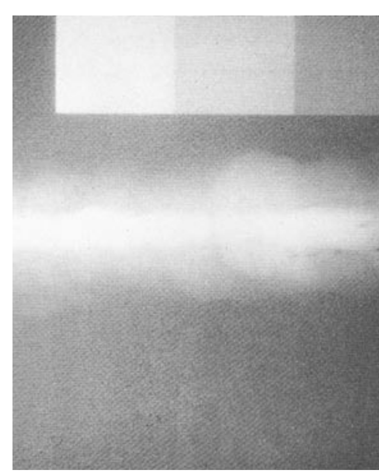
The radiograph has fog on one side or shows letter form shadows.

Probable Causes

1. White light is leaking from a slit in the safelight box.
2. The film has been allowed to stand under safelight illumination for too long a time or placed too near the safelight.
3. The film has been allowed to stand under safelight illumination too long a time or placed too near the safelight.
4. A lamp having a higher capacity than standard rating is used as the safelight source.

Corrective Action

1. Check the safelight filter periodically (every six months to once a year) and replace it if faded.
2. Observe safelight requirements, such as the prescribed lamp wattage and safelight-to-film distance, and complete work under safelight illumination as quickly as possible.
3. Check periodically to insure that the safelight is functioning under normal prescribed conditions.



Safelight Fog

FAULTS ASSOCIATED WITH HANDLING BEFORE DEVELOPMENT

Dirt Deposits or Stains on the Screen

Phenomenon

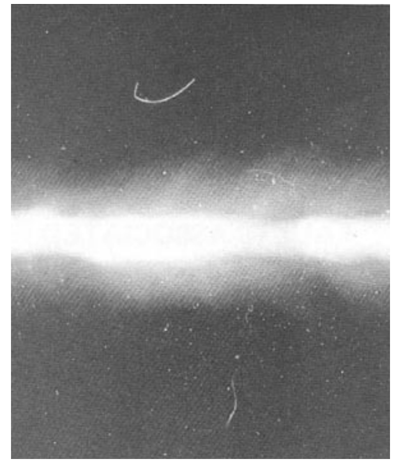
The radiograph has irregular shaped light spots.

Probably Cause

There are dirt deposits or stains on the intensifying screens.

Corrective Action

1. Keep the surfaces of intensifying screens clean and dry at all times.
2. Wipe the surfaces of intensifying screens with cleaner from time to time.



Spots on the Radiograph

Phenomenon 1

The radiograph has dark spots of a relatively low density.

Probable Cause

Water was spattered on the film.

Phenomenon 2

The radiograph has dark spots of high density.

Probable Cause

Developer solution was spattered over the film.

Phenomenon 3

The radiograph has light and dark spots of relatively low density.

Probable Cause

Stop bath solution was spattered over the film.

Phenomenon 4

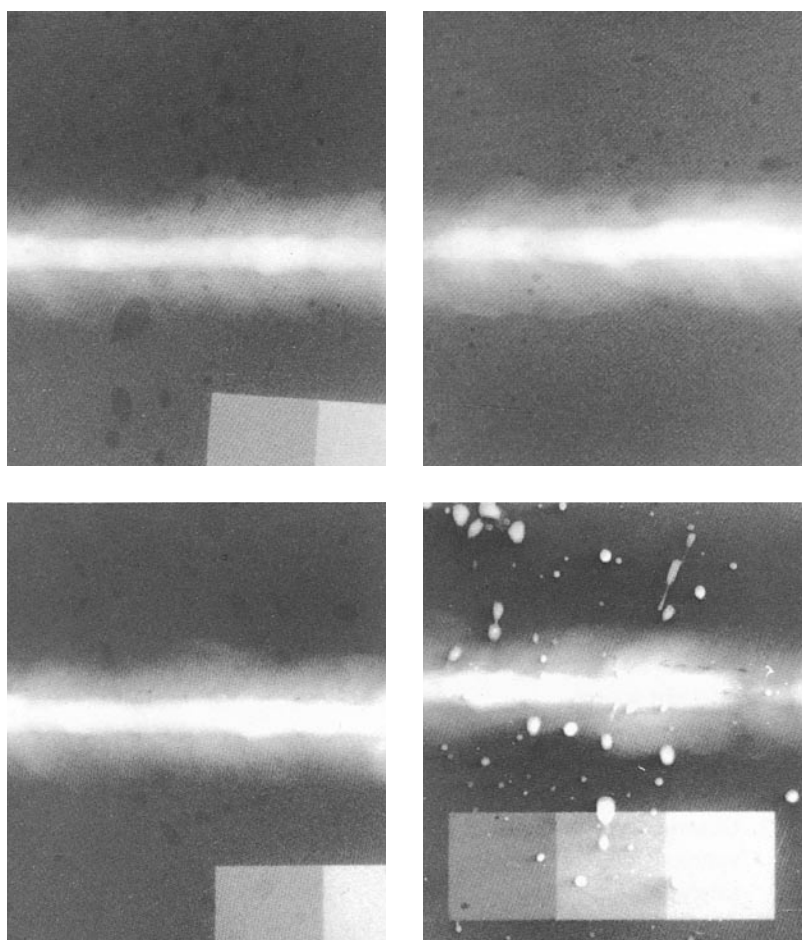
The radiograph has light spots which are barely developed.

Probable Cause

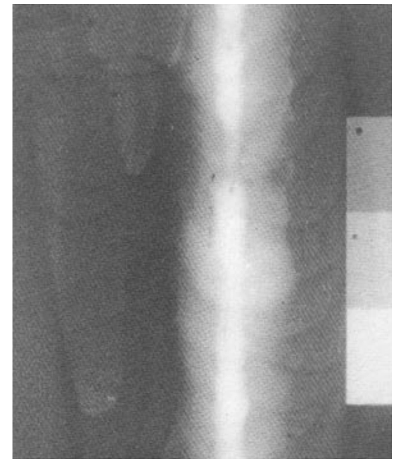
Fixer solution was spattered over the film.

Corrective Action

Handle films at such a distance from the processing area that water and processing solutions can not effect them.



FAULTS ASSOCIATED WITH DEVELOPMENT



Uneven Development

Phenomenon

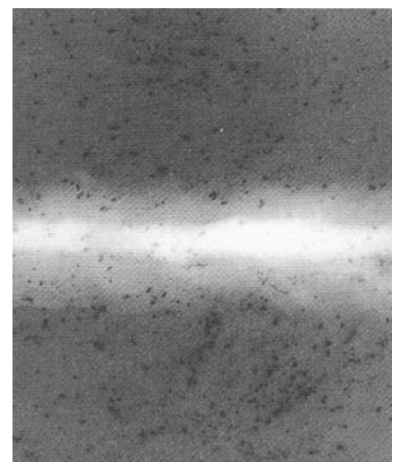
The radiograph exhibits streaks and mottle.

Probable Cause

Development proceeded locally.

Corrective Action

1. Comply with the recommended developer temperature.
2. Agitate the film adequately in the developer solution, especially in the early course of development.



Inadequately Dissolved Developer

Phenomenon

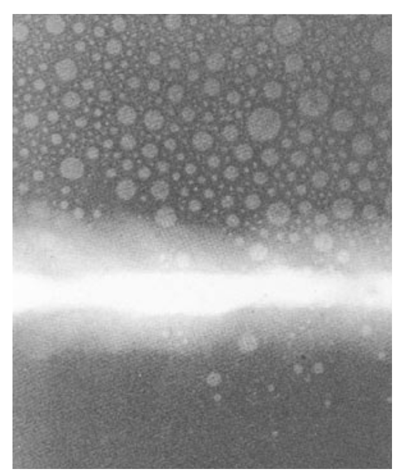
The radiograph has dark spots or black comets with tails.

Probable Cause

Chemical powder remains in the developer solution not being completely dissolved in water.

Corrective Action

1. When preparing the developer solution mix the powdered chemicals in hot water at about 50°C (122°F) and stir the solution until the chemicals are completely dissolved.
2. Prior to use make sure that the chemicals are completely dissolved.



Foam

Phenomenon

The radiograph has light, circular, marks of an indistinct contour.

Corrective Action

Avoid the creation of foam when the developer solution is agitated.

FAULTS ASSOCIATED WITH LOADING AND UNLOADING

Film Adhesion

Phenomenon

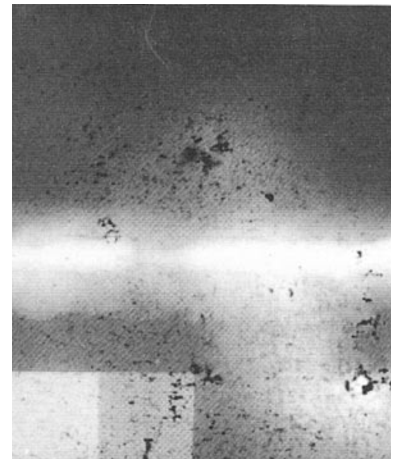
The radiograph has irregular shaped spot-like marks.

Probable Cause

The film loaded in the cassette adhered to the intensifying lead screen.

Corrective Action

1. Do not leave the film in a cassette for a long time during hot, wet seasons or in a hot place.
2. When the cassette is wet, leave it to dry in the shade, choosing a place where there is a good draft.



Static Marks

Phenomenon

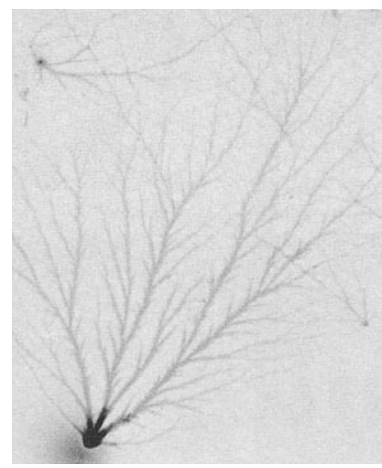
The radiograph has treelike or branching marks.

Probable Cause

Static marks result from the contact, peeling or friction of foreign matter caused by static electricity. They are apt to occur when the air is dry.

Corrective Action

1. Keep the darkroom air at the proper humidity levels (60 to 70% RH).
2. Any materials of rubber or synthetic fibers which are easily charged with static electricity should not be used near the film.
3. Handle the film gently.
4. Short the darkroom work bench to ground.



Kink Marks

Phenomenon

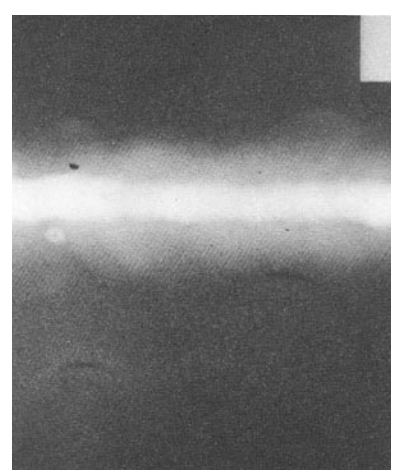
The radiograph has light or dark marks which are crescent shaped or irregular.

Probable Cause

The film was broken locally or sharply bent during handling. Dark marks appear when the film is sharply bent before exposure while sharp bending of an exposed area may become the cause of light marks.

Corrective Action

Carefully hold the edge of the film and avoid bending it.



FAULTS ASSOCIATED WITH POST DEVELOPMENT PROCESSING

Uneven Fixing

Phenomenon

The radiograph has light, irregular shaped marks or streaks.

Probable Cause

Fixing proceeded locally.

Corrective Action

1. Agitate the film in the fixer solution at frequent intervals, especially in early course of fixing.
2. Replace the fixer solution with a fresh one before it is exhausted beyond use.

Uneven Drying

Phenomenon

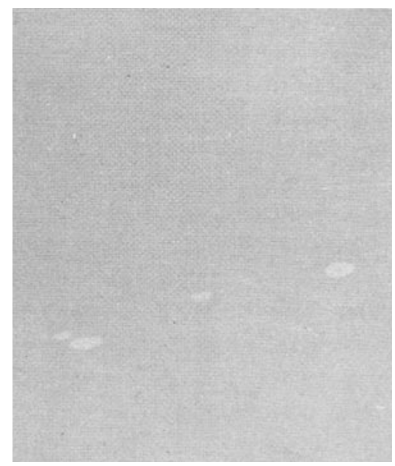
The radiograph has light, blurred lines or irregular shaped marks of film surface luster.

Probable Cause

Draining was incomplete and uneven so that the drying speed differed from one area to the other.

Corrective Action

1. Use Fuji *Driwel* wetting agent to drain the film evenly.
2. When hot air is used, gradually heat the air that is blown over the film.



FUJIFILM

FUJIFILM Corporation
7-3 Akasaka 9-chome, Minatoku, Tokyo 107-0052, Japan

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