DIRECT DIGITIZER

REGIUS MODEL 170

Technical Commentary

CODE NO. 0540

DD-741

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Konica Minolta Medical and Graphic, Inc

Introduction

This technical commentary explains to those intending to use the Direct Digitizer REGIUS MODEL 170, details of REGIUS MODEL 170 operating principles and image processing that are not explained in the user manual.

We will be happy if the understanding of REGIUS MODEL 170 functions gained by reading this manual, assists you use REGIUS MODEL 170 more effectively.

Hereafter, the REGIUS MODEL 170 will be referred to as the REGIUS 170, and the REGIUS CONSOLE CS-1 is referred to as the CS-1 in this document. The system that connects the REGIUS 170 and CS-1 is referred to as the REGIUS.

Contents

Chapter1

Outline

1.1 Basics of Analog/Digital Conversion

To digitize an X-ray image, use is made of two processes called sampling and quantization. These determine two image characteristics known as spatial resolution and intensity resolution respectively.

1.1.1 Sampling and Spatial Resolution

Sampling refers to the obtaining of discrete data elements (pixels) from spatially continuous data by reading values at chosen intervals. The interval used for sampling is called the sampling pitch.

The spatial resolution is the reciprocal of the sampling pitch, and expresses the number of pixels within the image per unit of length.

Pixel:
The smallest element of a sampled image. Each pixel is located on a sampling coordinate point.

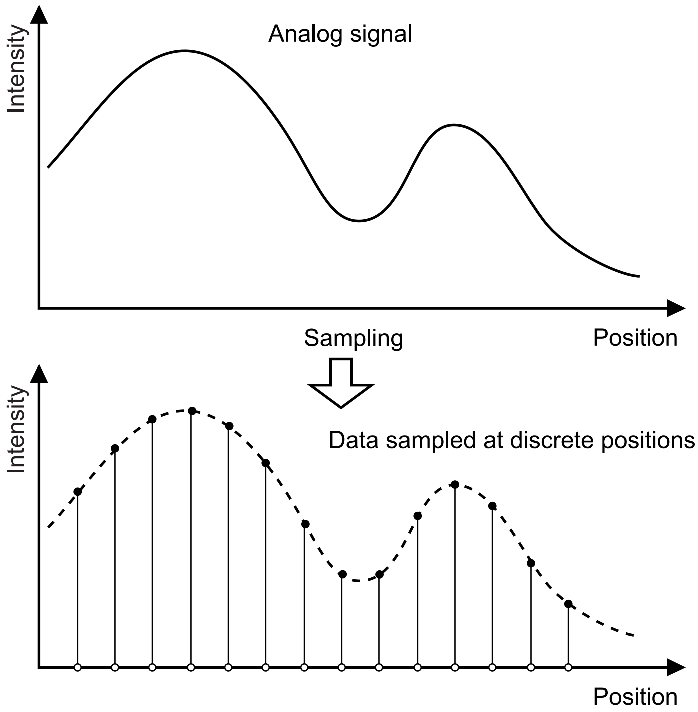


Figure 1-1-1 Sampling

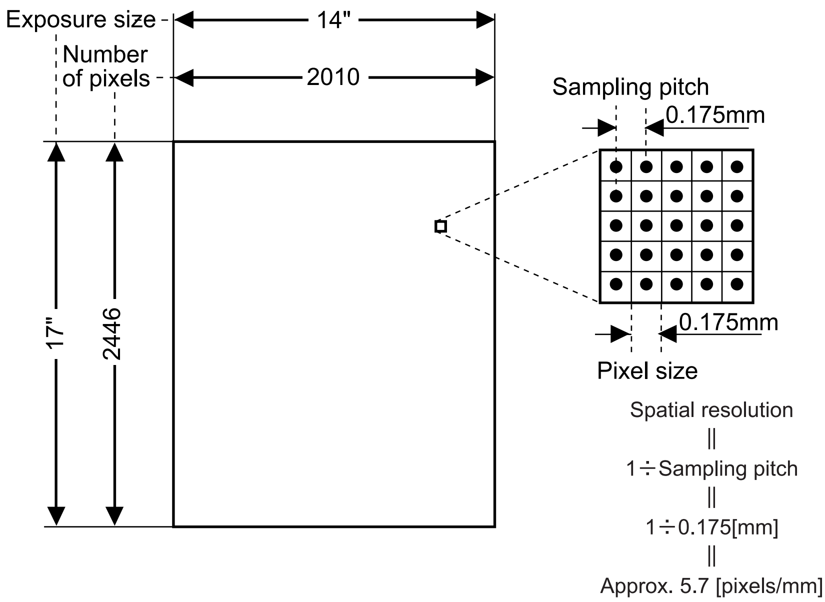


Figure 1-1-2 Sampling pitch and pixel size

The following images show examples of an original image sampled at different resolutions.

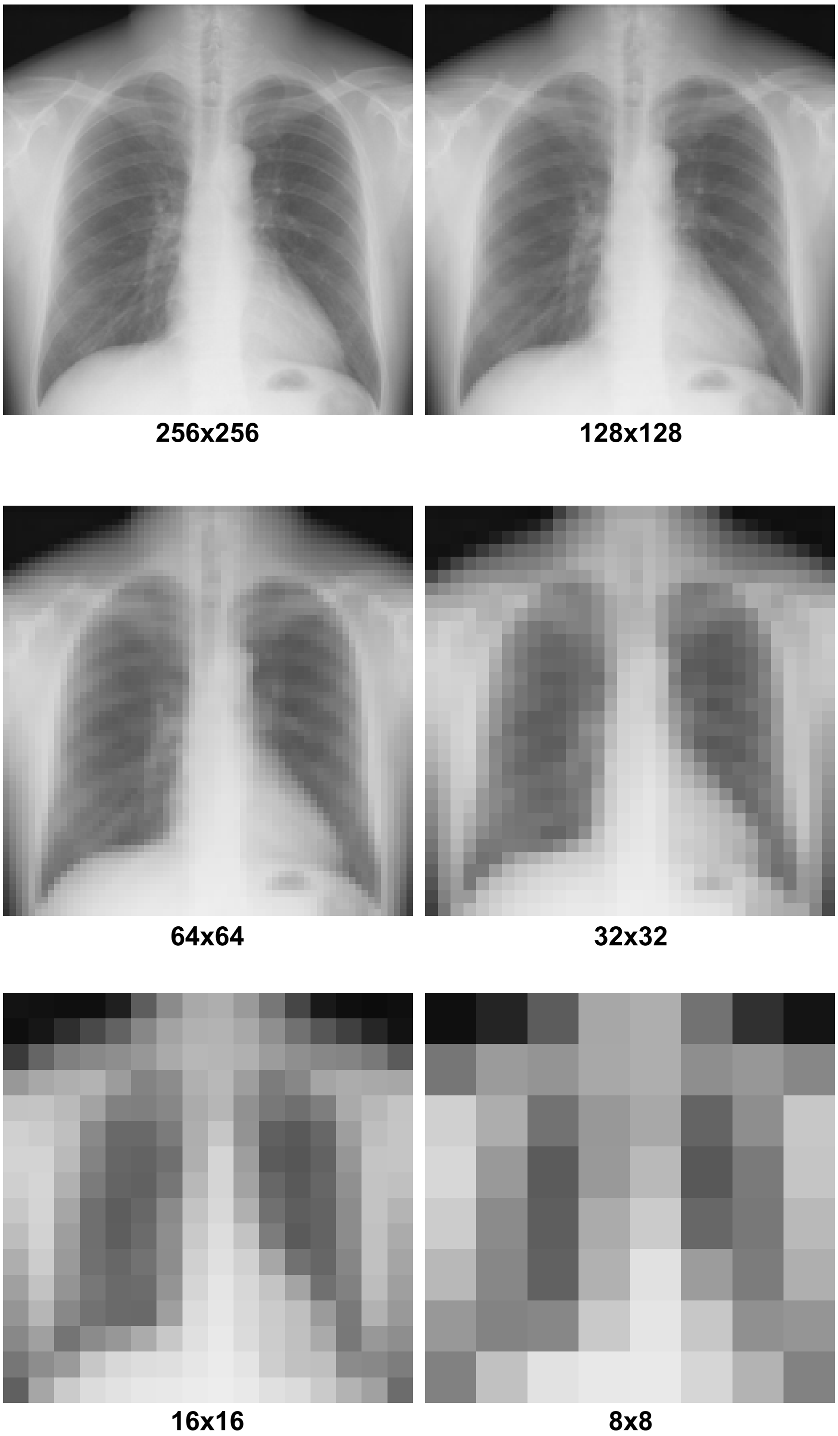


Figure 1-1-3 Number of pixels and image quality

The REGIUS 170 reader has a maximum spatial resolution of 11.4 pixels/mm. In the field of large area photostimulated fluorescence-based digital radiography, this gives it the highest level of spatial resolution.

1.1.2 Quantization and Gradation Levels

Quantization refers to the obtaining of discrete values of data from continuously
variable data (such as intensity or brightness) by reading values of chosen intervals.
The individual values for intensity that can be obtained through quantization are referred to as pixel value, gray level or quantization level.
The number of possible pixel values is referred to as the number of gradation levels (or number of gray levels or number of quantization levels).
In general, for reasons related to data processing, the number of gradation levels used for quantization is very often a power of two. This can be expressed as:
1024 levels = 2^{10} levels = 10 bits, 4096 levels = 2^{12} levels = 12 bits etc.

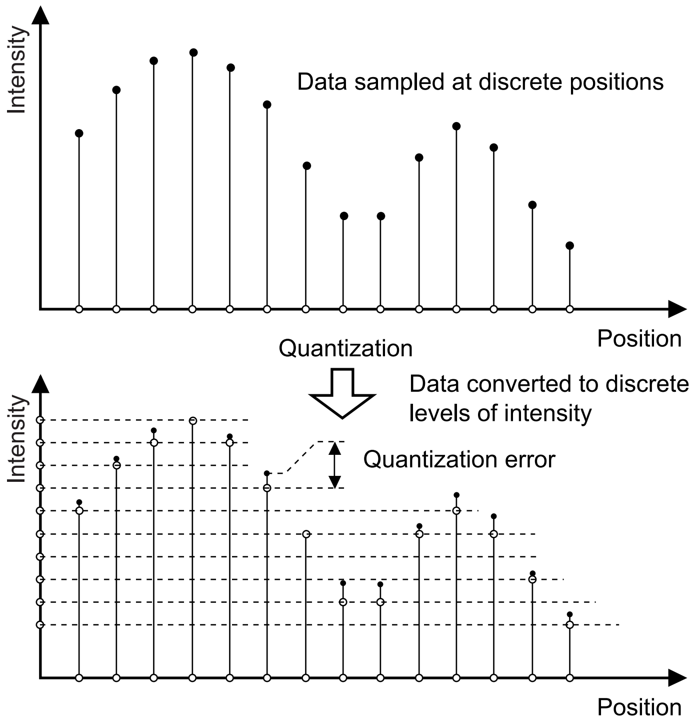


Figure 1-1-4 Quantization

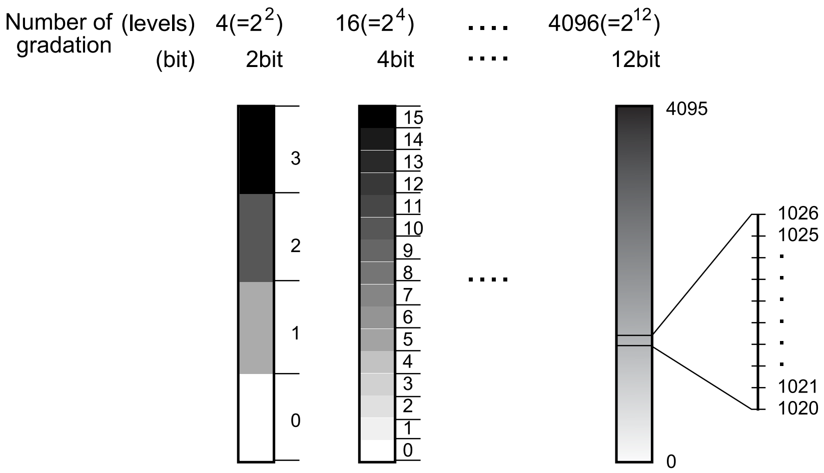


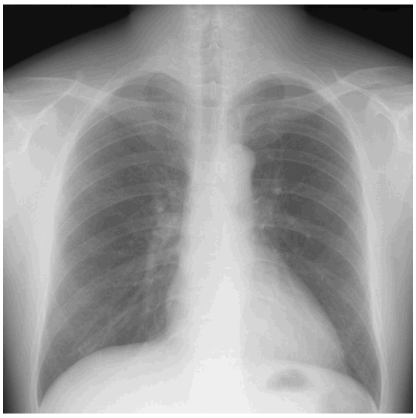
Figure 1-1-5 Number of gradation levels

The number of gradation levels used for quantization is also referred to as density resolution. A low density resolution (few gradation levels), reduces the capacity to reproduce smooth changes of image tone and results in the appearance of false contours.

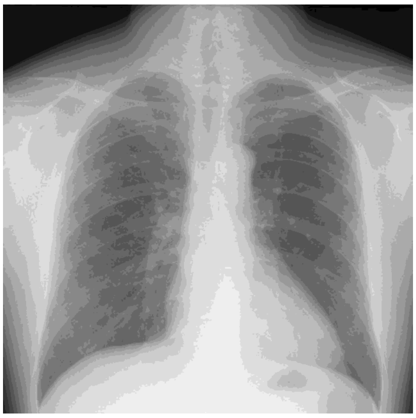
256levels

128levels

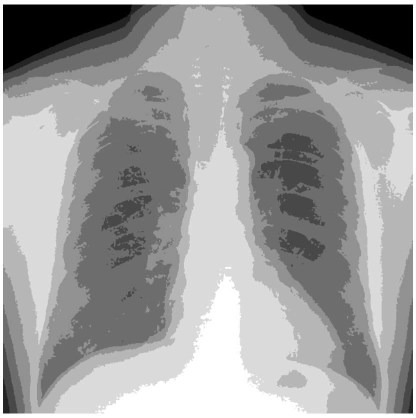
64levels



32levels



16levels



8levels

Figure 1-1-6 Number of Gradation Levels and Image Quality

Images read with REGIUS are quantized using 12 bits giving 4096 gradation levels. It is generally considered that if the number of gradation levels is between 10 bits (1024 levels) to 12 bits (4096 levels), deterioration of image quality due to quantization when an X-ray image is reproduced, is too small to be a problem.

1.1.3 Image Data Size

The amount of image data obtained when an X-ray image is digitized is given by the expression below.

Image data size = Pixels in horizontal direction x Pixels in vertical direction x Bits per pixel

REGIUS performs quantization using 12 bits per pixel, but most computers internally process data in 8 bit units, so the pixels are handled as 16 bits of data.

For example, in the case of an exposure of size of 14x14 and a read pixel size of 175 µm, the image data size would be found as follows:

2010 x 2010 x 16	=	64641600	bits (bit)
		8080200	bytes (B)
		Approx. 7890	kilobytes (kB)
			(7890.820315kB)
		Approx. 7.7	megabytes (MB)
			(7.70587921142578125MB)

The relationship between the REGIUS 170 exposure size, pixel size, and image data size is explained in detail in chapter 3.

1.2 Principles of Photostimulated Luminescence

The REGIUS 170 (or CS-1) is a system in which the phenomenon of PSL (photostimulated luminescence) is applied to X-ray radiography, and the system belongs to the field of CR (computed radiography).
In the PSL phenomenon, when external stimulation of a florescent material has been terminated and emission of light from the material has ceased, illuminating the material with light of wavelength longer than that of the emitted light, leads to light once more being emitted.
Materials exhibiting the PSL phenomenon are called photostimulable flourescent materials.

The following figure provides a conceptual view of the REGIUS 170 image acquisition process.

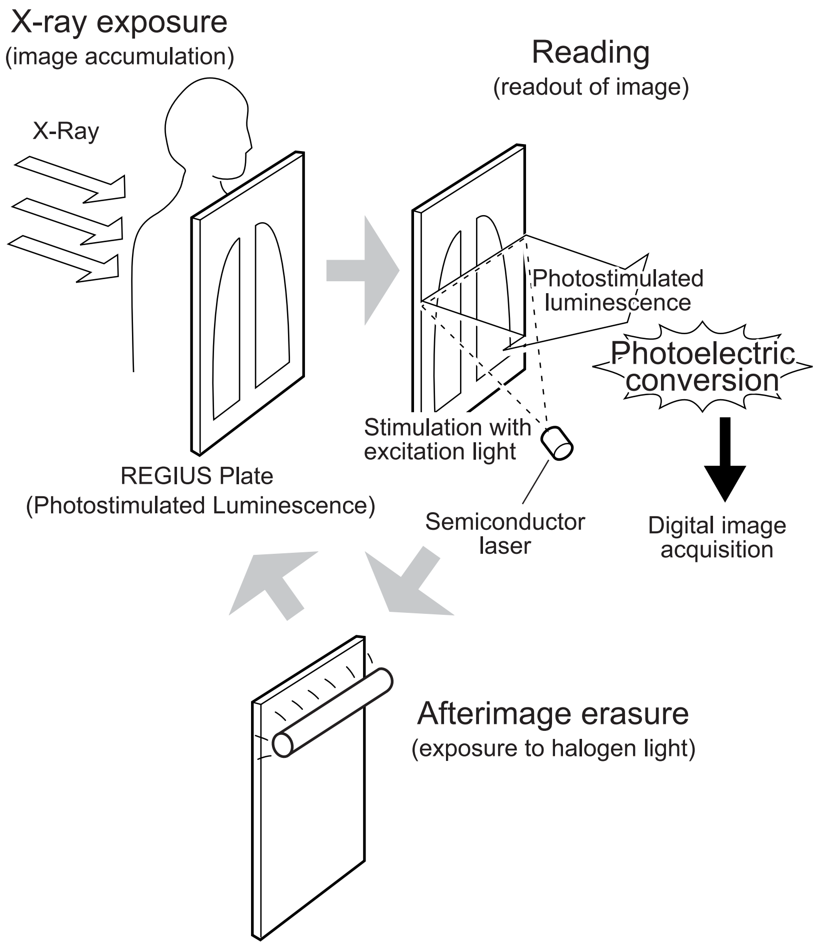


Figure 1-2-1 Photostimulated luminescence

1.3 Principles of Image Reading

Figure 1-3-1 Steps REGIUS uses to read an image

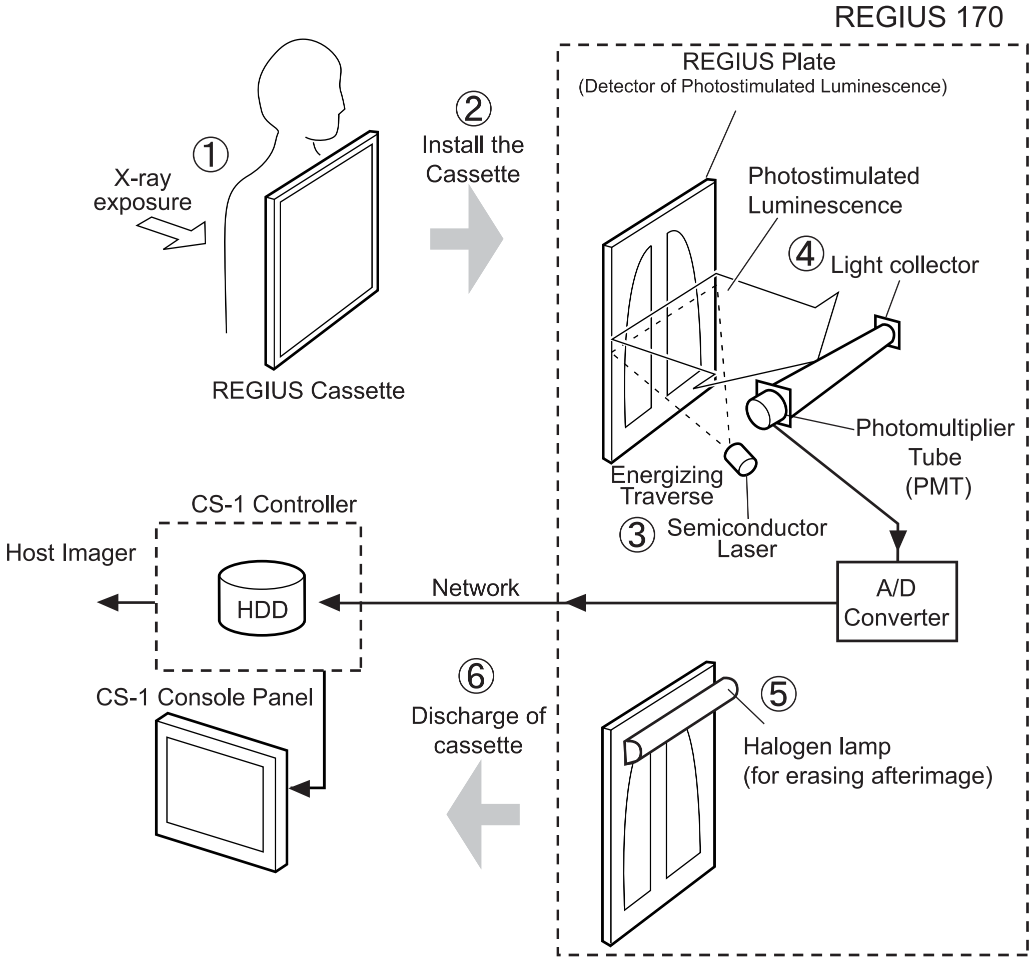


Figure 1-3-1 Steps REGIUS uses to read an image

① The X-ray through the subject is exposed on the REGIUS plate (detector of photostimulated luminescence) in the REGIUS cassette and is recorded as an X-ray image.

② When the REGIUS cassette is inserted into the REGIUS 170, the REGIUS Plate is separated from the cassette and transferred to the reading instrument.

③ Infrared rays from the semiconductor laser traverse the REGIUS plate, then an intensive luminescence (photostimulated luminescence), which is proportional to the accumulated X-ray energy, will be radiated.

④ This photostimulated luminescence is focused at the photomultiplier tube (PMT) and converted from light signals to electrical signals and digitized via analogue/digital conversion. The time dependent X-ray image is then transferred to the CS-1 via the network. (Reading)

⑤ The REGIUS plate is exposed to halogen light to delete the remaining image. (Delete)

⑥ The REGIUS plate is returned to the cassette and discharged from the REGIUS 170.

This series of operations (exposure → installation → reading → delete → discharge) permits re-usage of the REGIUS plate.

Digitized X-ray images are displayed on the CS-1 console panel (LCD) and temporarily recorded on the hard disk (HDD) of the CS-1 controller.
After being confirmed on the console panel, the image recorded on the HDD will be transferred to the imager and to the host computer based on the settings of the CS-1.

Chapter2

Detector Technology

2.1 Development Concepts

Use of digital imaging systems to aid diagnosis in hospitals is becoming commonplace since the arrival of the new information technology era. Computed radiography (CR) systems, which are X-ray image digital input systems, have achieved diagnostic functionality equivalent to that of hitherto film/screen systems and are spreading at a remarkable speed. A variety of new technologies enabling short processing times and compact equipment are integrated into the cassette-type CR REGIUS 170, and these technologies are based on the completely new concept of ultra dispersion. The characteristics of the photostimulable fluorescent plate, that being responsible for recording and reading of the image is at the heart of the CR system, are determined by the characteristics of the fluorescent material that is used. Until recently, for plates a BaFBr fluorescent material containing the elements barium (Ba) and bromine (Br) was mainly used. The BaFI plate was developed in which the use of bromine in the original BaFBr was replaced by more effective iodine absorbing X-rays. And this BaFI plate is applied to the REGIUS plate of the REGIUS 170. A plate with greater capacity to absorb X-rays, reduces the image X-ray quantum mottle, so can greatly contribute to improved CR image quality. Furthermore, the combination of the bright luminescence of the BaFI fluorescent material, a plate structure which effectively takes advantage of it, plus a new type cassette, results in a system suitable for all types of diagnosis.

The details of the REGIUS Plate, which is used in the cassette-type REGIUS 170, will be explained in this chapter.

2.2 Characteristics of Photostimulable Fluorescent Material

2.2.1 Composition and Mechanism of Luminescence

The photostimulable material applied to the REGIUS plate is the BaFI compounds, which contains small amounts of Eu. This compound has a square crystal lattice PbFCl type structure and is an ionic crystal with a regular structure perpendicular to the c axis. The minute quantity of Eu ions which provide sites for photostimulated luminescence, adopt a layout in which they substitute for Ba sites in the BaFI host crystal. Figure 2-2-1 shows the light emission mechanism of the BaFI:Eu photostimulable florescent material. It shows a halogen hole in the BaFI crystal that in response to X-ray irradiation captures a conductive electron so as to form an F center.
It is believed that irradiation of this F center with photostimulation excitation light, liberates the captured electron, causing an Eu ion which serves as a site for light emission to be restored to its original state, resulting photostimulated luminescence.

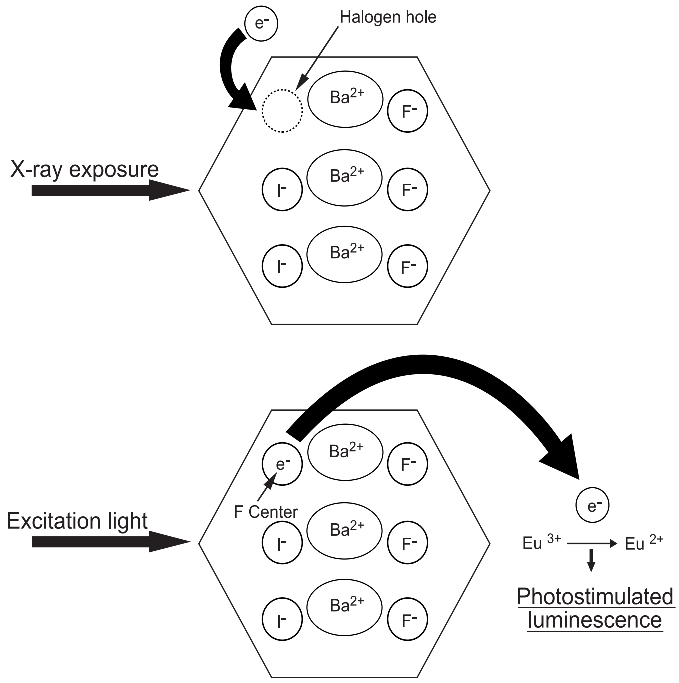


Figure 2-2-1 Light emission mechanism of the BaFI:Eu photostimulable fluorescent material

2.2.2 Photostimulable Luminescent Spectrum and Photostimulation Excitation Spectrum

Figure 2-2-2 shows the photostimulable luminescent spectrum and photostimulation excitation spectrum of the BaFI:Eu photostimulable florescent material. The photostimulable luminescent spectrum and photostimulation excitation spectrum are properties of the florescent material. It can be seen that the photostimulation excitation spectrum of the BaFI:Eu photostimulable florescent material extends over a range of wavelengths that allows excitation by the wavelength of a semiconductor laser. The photostimulated light is focused by a condenser into a photo multiplier tube which performs a photoelectric conversion. For this purpose, there needs to be sufficient distance between the photostimulable luminescent spectrum and the photostimulation excitation spectrum, and the photostimulable luminescent spectrum needs to match the spectral sensitivity of the photo multiplier tube. The BaFI:Eu photostimulable florescent material adequately satisfies these conditions.

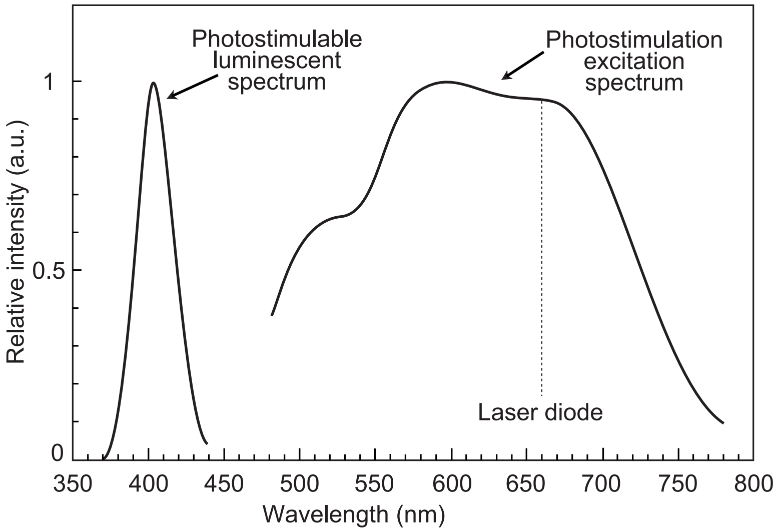


Figure 2-2-2 Photostimulable luminescent spectrum and photostimulation excitation spectrum

2.2.3 Photostimulated Luminescence Time Response Characteristics

When the photostimulable florescent material is irradiated with excitation light after being exposed to X-rays, it immediately produces photostimulated luminescence, and when the excitation is stopped, the photostimulated luminescence also stops. The response characteristics of this photostimulated luminescence show values characteristic of and dependent on the photostimulable florescent material. Since a time sequential signal based on laser scanning of image information is read out for CR use, it is important for the characteristics to allow a response that is as faithful as possible to the on/off stimulation of the laser light (excitation light).

Figure 2-2-3 shows the PSL time response characteristics of the BaFI:Eu photostimulable florescent material. When the laser light (input waveform) has a long excitation time as shown in Figure 2-2-3, the rise and decay times are about the same, but in this document we will not distinguish between rise and decay times and simply speak of response characteristic. In Figure 2-2-3, the response characteristic of the BaFI:Eu photostimulable florescent material is about 0.6μsec.

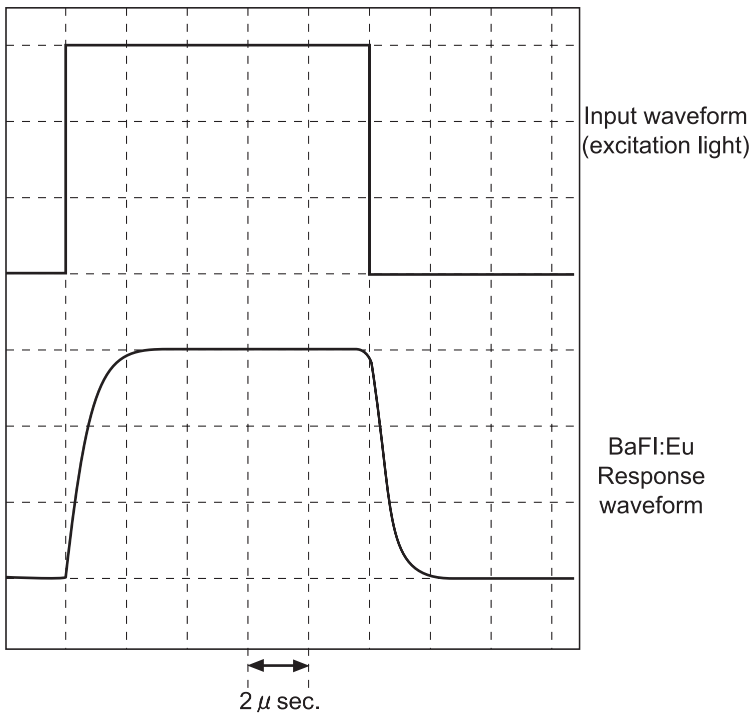


Figure 2-2-3 PSL time response characteristics of BaFI:Eu photostimulable florescent material

2.2.4 STRUCTURE OF THE REGIUS PLATE

One characteristic of the photostimulable florescent detector is the possibility for it to be repeatedly used.However, to repeatedly use the detector, the photostimulable florescent layer needs to be protected from physical damage or chemical deterioration that could be caused by external factors. Generally a protective film consisting of a few tens of microns of PET etc. would be placed over the florescent layer using adhesive.With earlier technology, use would either be made of a thick protective film which would cause significant deterioration of image quality, or of a thin protective film which would be vulnerable to damage by external factors.

The REGIUS plate uses a special barrier film with high optical transparency that causes little loss of the image signal. Furthermore, a layer is inserted between the protective layer and the fluorescent layer that prevents scattering of excitation light. Use of this new technique allows the florescent layer of the plate to be protected from external damage while maintaining high image sharpness.

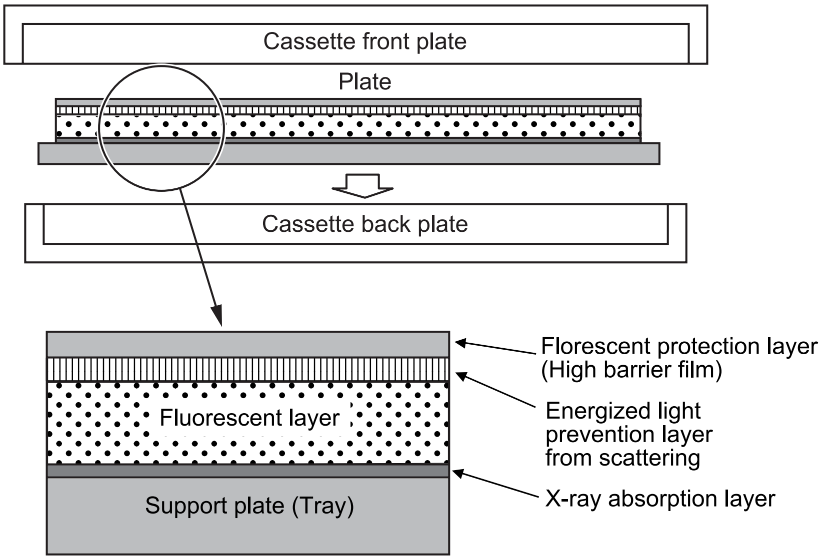


Figure 2-2-4 Detector construction

- **Role of the Layer that Prevents Scattering of Excitation Light**

  Insertion of a layer between the protective layer and the fluorescent layer that prevents scattering of excitation light, avoids scattering of excitation light within the protective layer and improves sharpness.

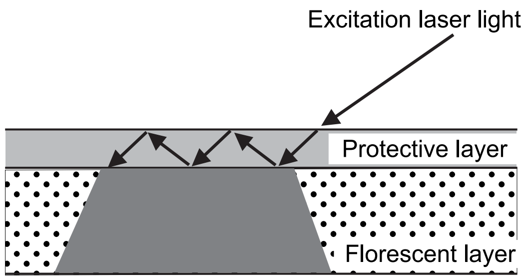


Figure 2-2-5 Without a layer to prevent scattering of excitation light

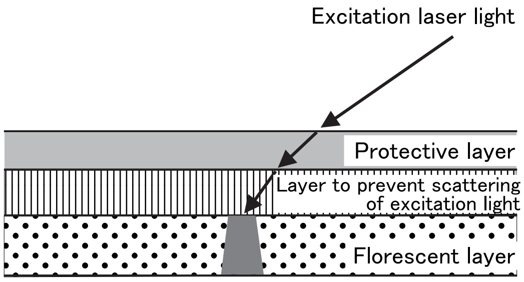


Figure 2-2-6 With layer to prevent scattering of excitation light

Physical properties and characteristics of the REGIUS Plate (both for general plate and for mammography plate) are described in "2.3 PHYSICAL FEATURES OF THE REGIUS PLATE".

- **Mammography Detector Characteristics**

During development of a plate for mammography use, Konica aimed for cooperation with photographic equipment for extraction of chest walls, conventional operation and adequate implementation image quality. Concretely to allow for chest wall extraction, a fold back seal structure was used so that image losses during exposure could be minimized and be less than 2mm required by the IEC standard. Furthermore, conventional operation was achieved by allowing use of AEC settings and ensuring the X-ray dose passing through the detector complied with conventions. To achieve image capabilities providing sufficient sharpness for both extraction and discrimination, use has been made of a fine grain high fill ratio detector.

*** Structure of fold back seal**

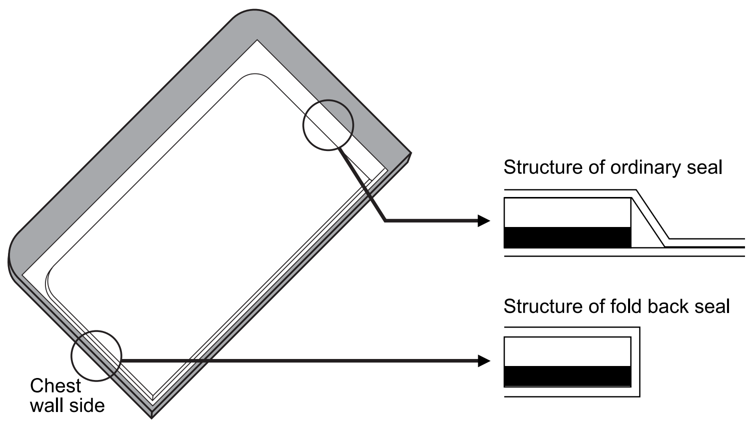


Figure 2-2-7 Cross Section of Plate

*** Increasing fill ratio of fine grain fluorescent material**

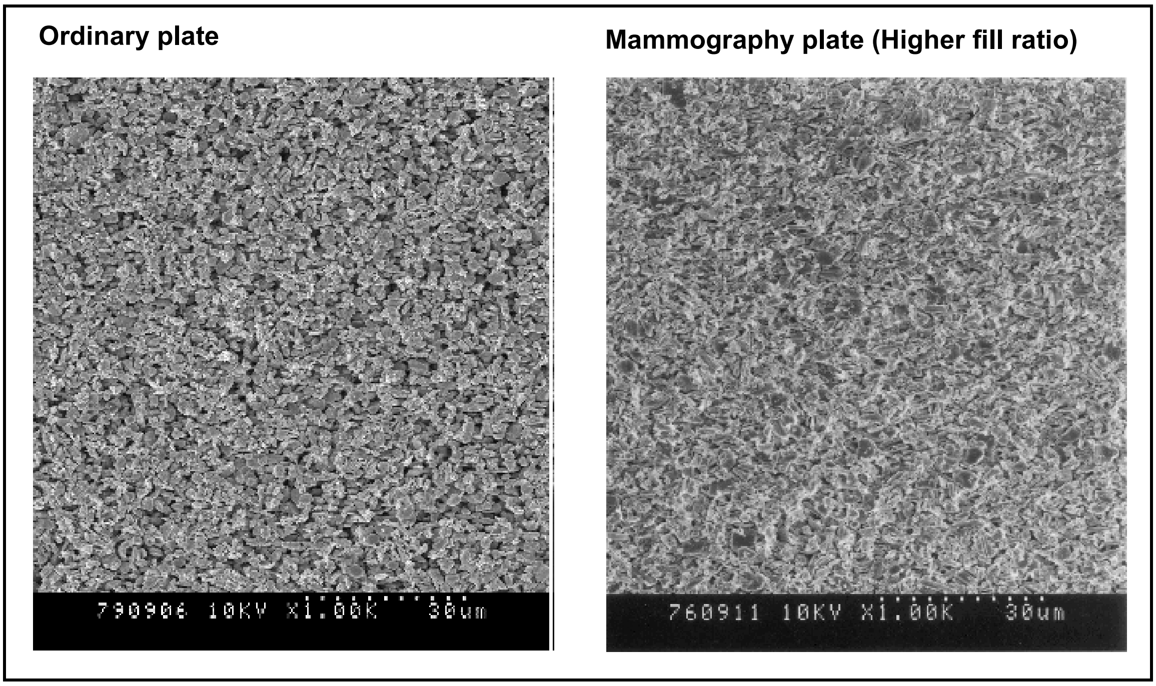


Figure 2-2-8 Cross section of fluorescent layer

2.2.5 X-Ray Absorption Characteristics

Figure 2-2-9 shows the BaFI:Eu photostimulable florescent material Xray absorption characteristics.

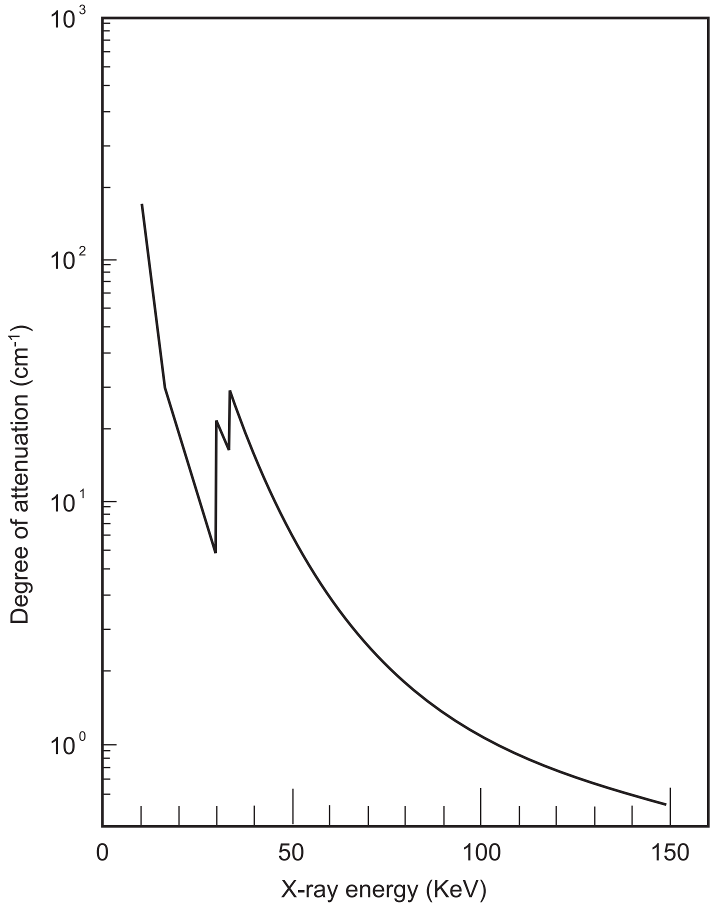


Figure 2-2-9 X-ray absorption characteristics of BaFI:Eu photostimulable florescent material

2.2.6 Dynamic Range

Figure 2-2-10 shows the dependency of photostimulable luminescent light emission on incident X-ray dose when the BaFI:Eu photostimulable florescent detector is irradiated with X-rays.

As can be seen from the diagram, good linearity is displayed over a wide range of more than four figures. Such a wide dynamic range could not be obtained with earlier screen or film systems and is a major advantage offered by the REGIUS 170.

In the REGIUS 170, the light emitted through luminescence is converted by a photomultiplier to an electrical signal, and because of this, the whole of the wide dynamic range shown in the diagram can be made available as effective diagnostic information.
From this, it is possible to obtain the ideal diagnostic digital X-ray images through the use of the CS-1 automatic gradation processing and other image processing as explained later.

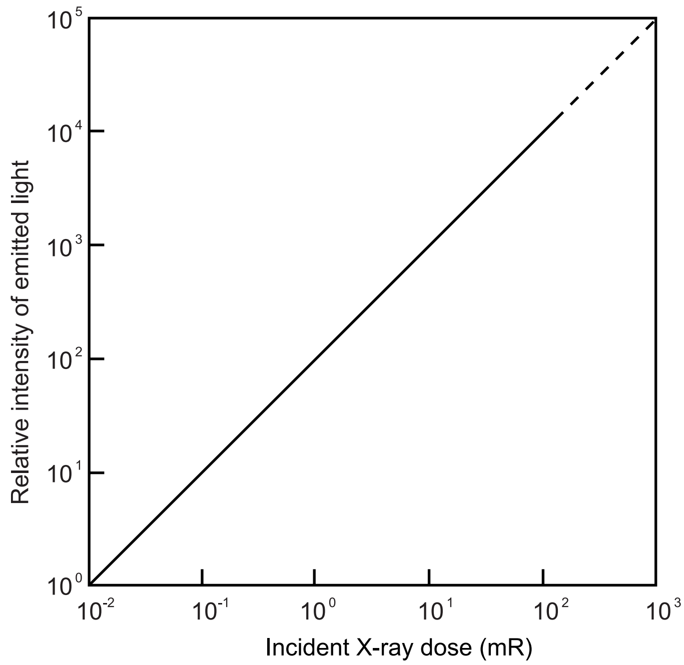


Figure 2-2-10 Dependency of photostimulable luminescent light emission on incident X-ray dose

2.2.7 Fading Characteristics

Figure 2-2-11 shows the relation between the fading value (relative intensity of emitted light) and time elapsed following X-ray irradiation. Fading refers to the phenomenon that image information accumulated on the detector after exposure to X-rays, reduces depending on how much time elapses until the detector is read. This occurs because as time passes, the electrons that have been captured by the F centers following X-ray irradiation, are liberated and become unable to contribute to photostimulated luminescence.

In the case of the REGIUS plate, consideration has been given to the time required to remove and read the cassette following exposure. During this time, little degradation of the image occurs, and the detector is one that it can be repeatedly used.

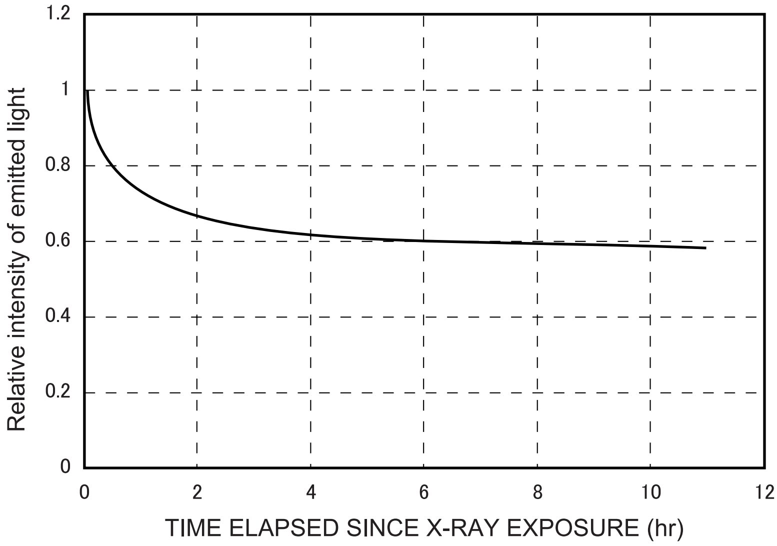


Figure 2-2-11 Decline in intensity of photostimulated luminescent intensity versus elapsed time

2.2.8 Afterimage Erasure Characteristics

Figure 2-2-12 shows the afterimage erasure characteristics of the BaFI:Eu photostimulable florescent material. Because the BaFI:Eu photostimulable florescent material has excellent afterimage erasure characteristics, the erase lamp load has been reduced, allowing production of a more compact reader. Furthermore, the time required for erasure has also been reduced, which has allowed an effective reduction in the cycle time for repeated expose → read → erase cycles.

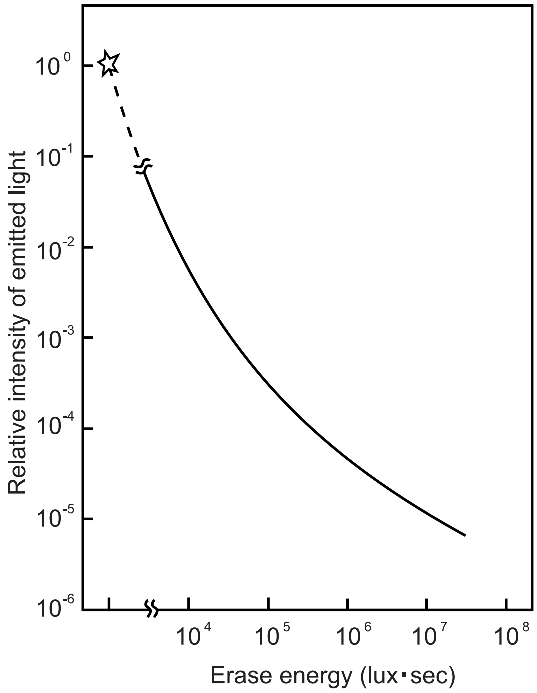


Figure 2-2-12 Afterimage erasure characteristics of photostimulable florescent material

2.2.9 Durability of the Fluorescent Plate

With mechanisms in which transport rollers etc. are used to transport the detector, the surface of the protective film would be subjected to physical damage which would promote the deterioration of image characteristics.
In contrast to this, the detector is transported without surface contact in the REGIUS 170, which is a unique technology, thus preventing damage to the surface.

Assuming use over a long period of time, Figure 2-2-13 shows the change of image sharpness versus elapsed time. Due to the adoption of special barrier film and luminescent resin coating, the fluorescent plate maintains initial sharpness of 90% after two years of operation and under the conditions of 30°C, 80% relative humidity (RH). Photostimulated liminescent intensity deteriorates very little as well.

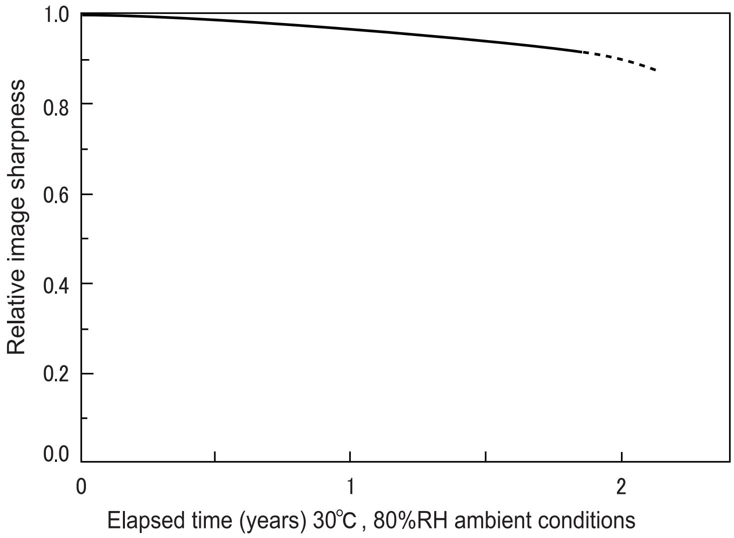


Figure 2-2-13 Change of image sharpness versus elapsed years

2.3 PHYSICAL FEATURES OF THE REGIUS PLATE

2.3.1 General Plate

MTF

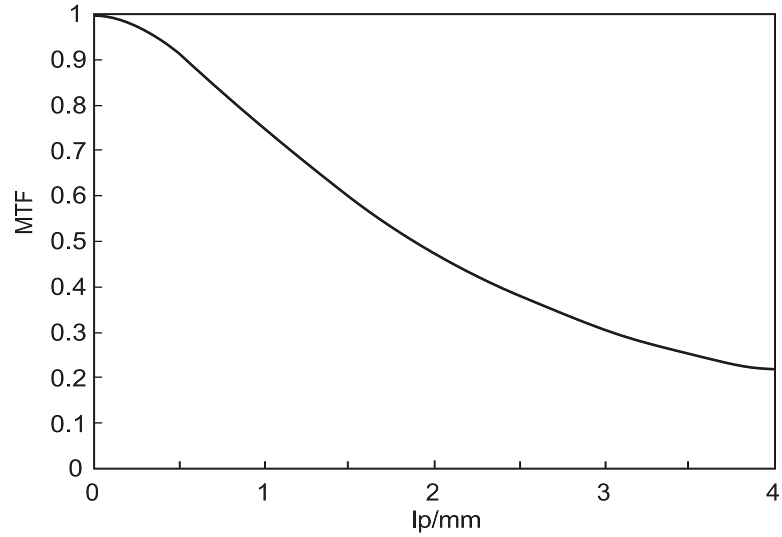


Figure 2-3-1 MTF

W.S

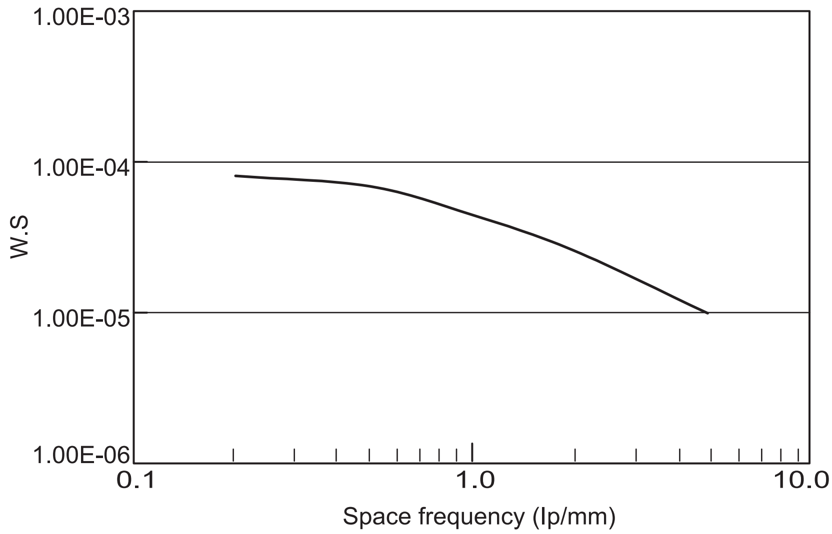


Figure 2-3-2 W.S

Glare

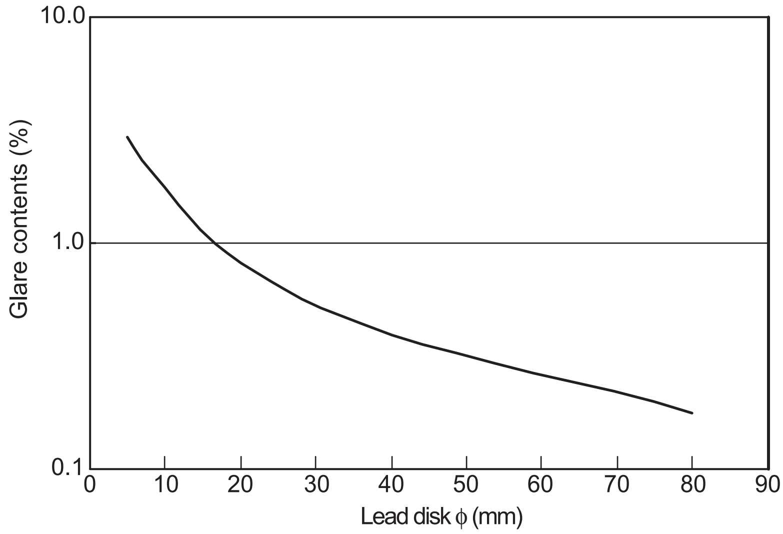


Figure 2-3-3 Glare (Lead disk method)

DQE

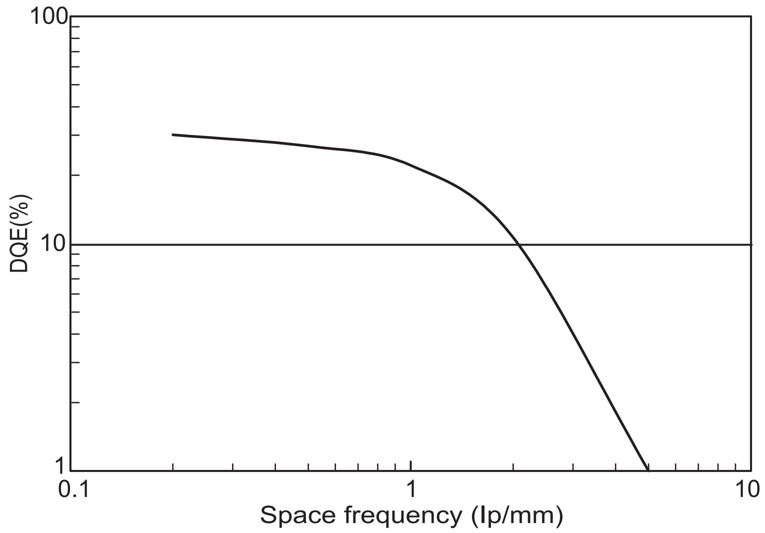


Figure 2-3-4 DQE

2.3.2 Mammography Plate

MTF

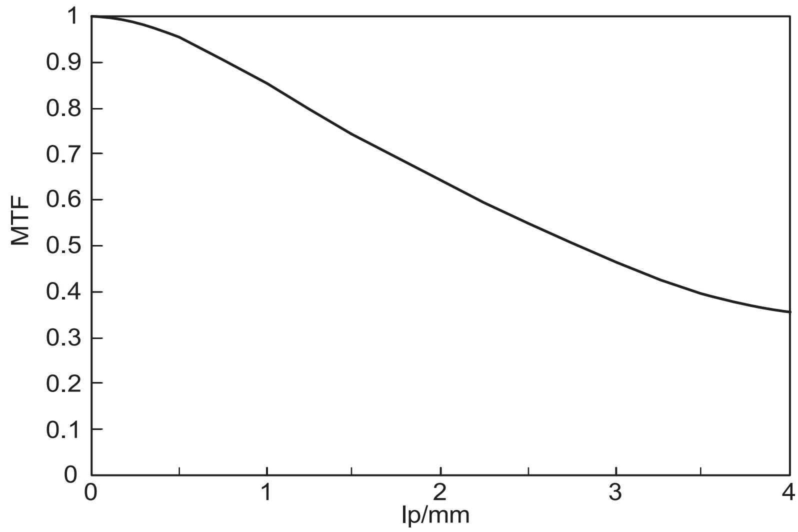


Figure 2-3-5 MTF

W.S)

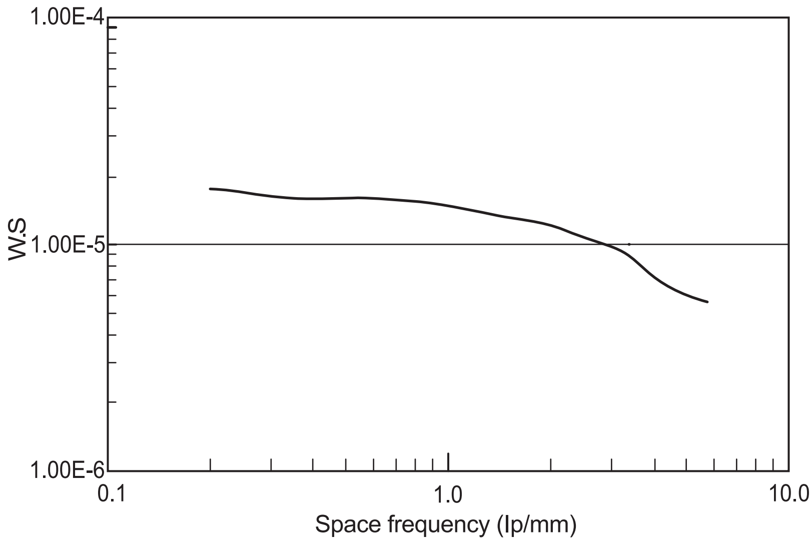


Figure 2-3-6 WS

Glare

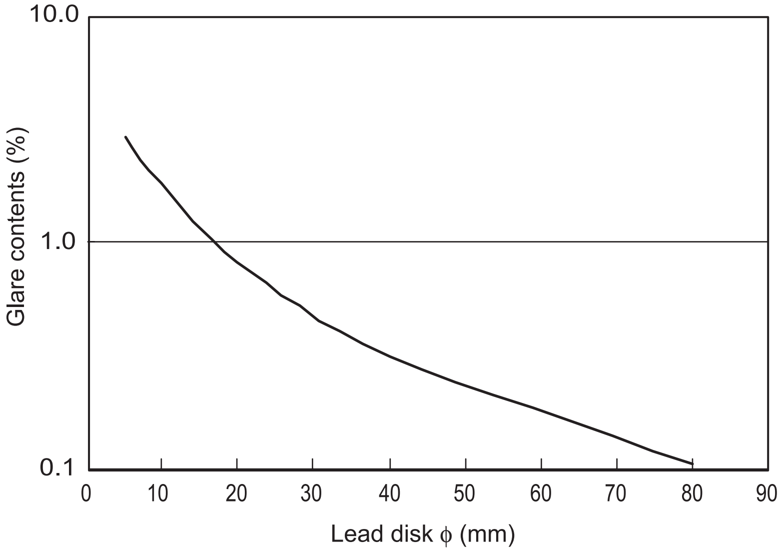


Figure 2-3-7. Glare (Lead disk method)

2.4 Structure of Cassette

■ Cassette for general exposure

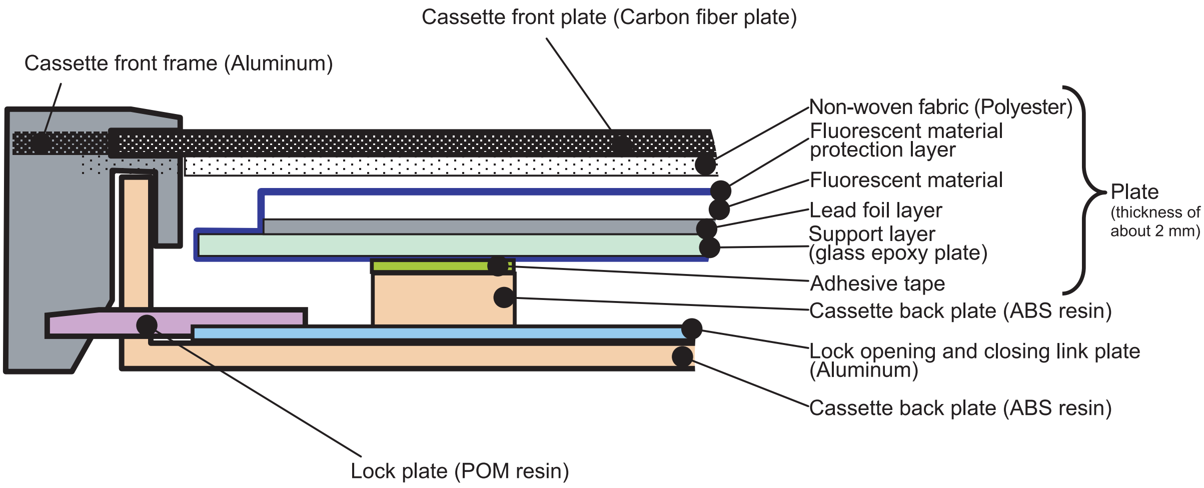
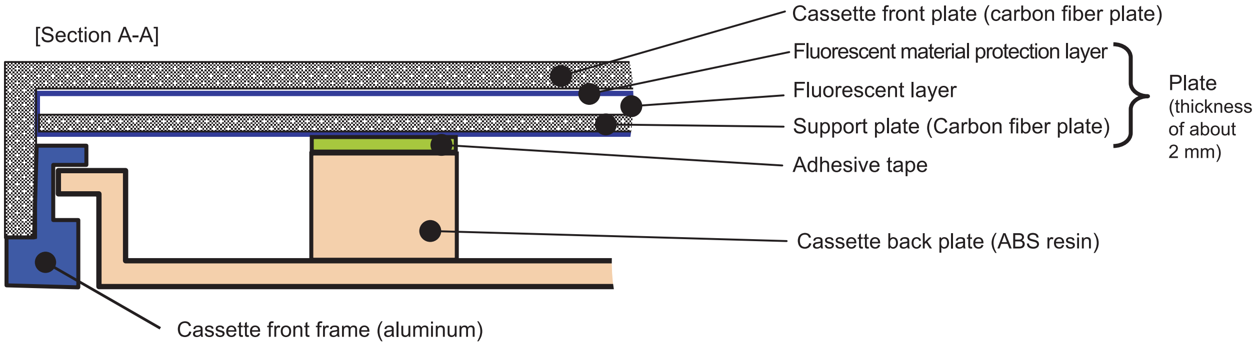


Figure 2-4-1. Structure of cassette for general exposure

■ Cassette for mammography exposure



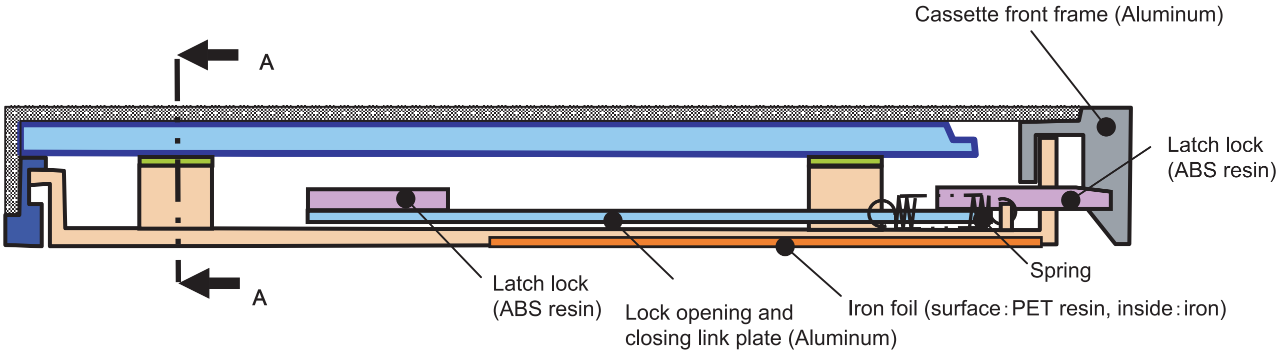


Figure 2-4-2. Structure of cassette for mammography exposure

■ Long exposure cassette

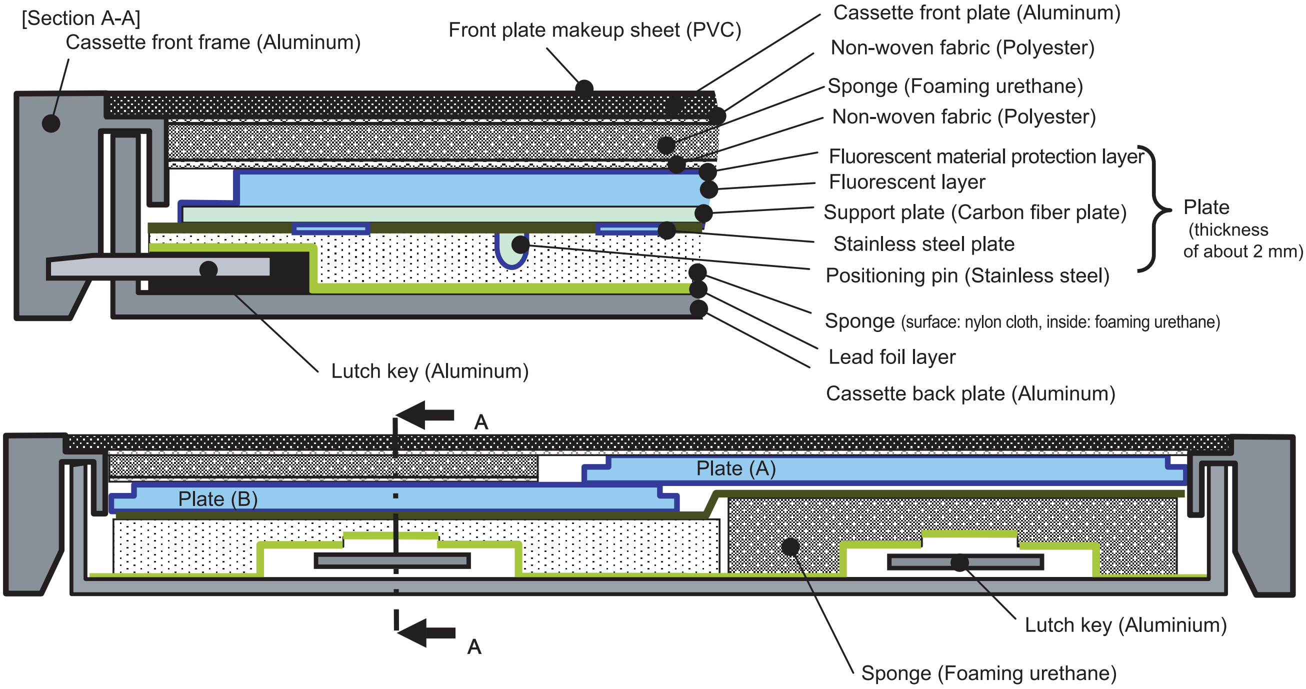


Figure 2-4-3. Structure of long exposure cassette

■ Linac graphy exposure cassette

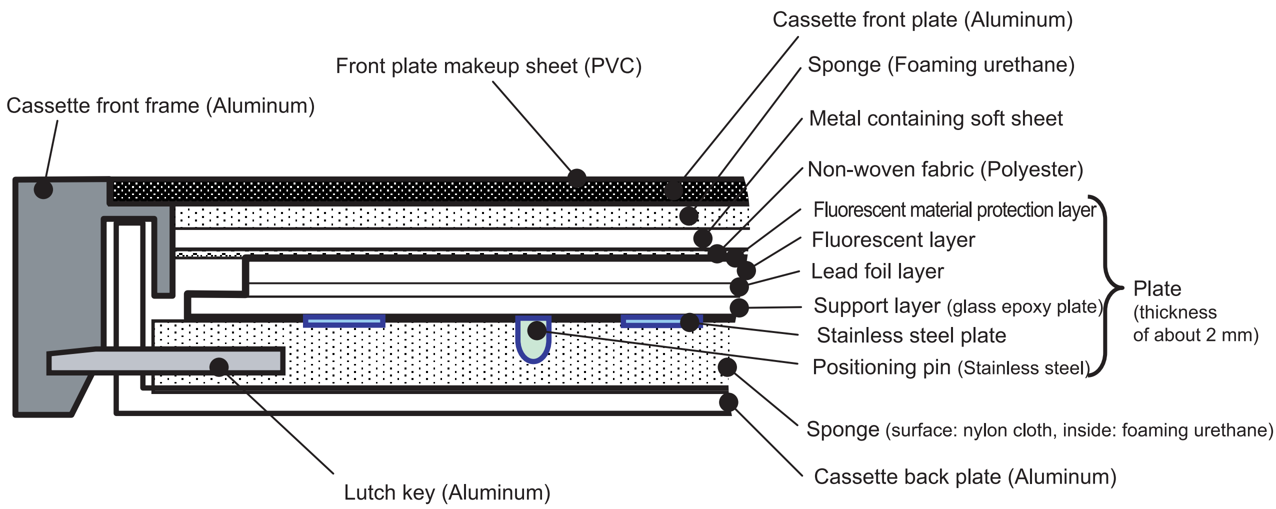


Figure 2-4-4. Structure of linac graphy exposure cassette

Chapter3

Image Acquisition

3.1 REGIUS Read Sensitivity

3.1.1 Digitizer Range

The correlation between the X-ray irradiation dosage and luminescent intensity shows excellent linearity over four figures for the REGIUS plate (BaFI: Eu photostimulated luminescent detector) of the REGIUS 170 and is applicable in the diagnosis as useful information over the entire range. However, in normal X-ray radiography, the distribution of X-ray information required for diagnosis does not extend over this entire dynamic range but is rather, in almost all cases, maldistributed within a particular region. If it is, the entire dynamic range does not need quantization, but the range where efficient X-ray information exists should be digitized.

For this reason, the REGIUS 170 digitizes an arbitrary four-figure range of the arrived X-ray doses by 12 bits (4096 levels) depending on exposure method and exposed part.

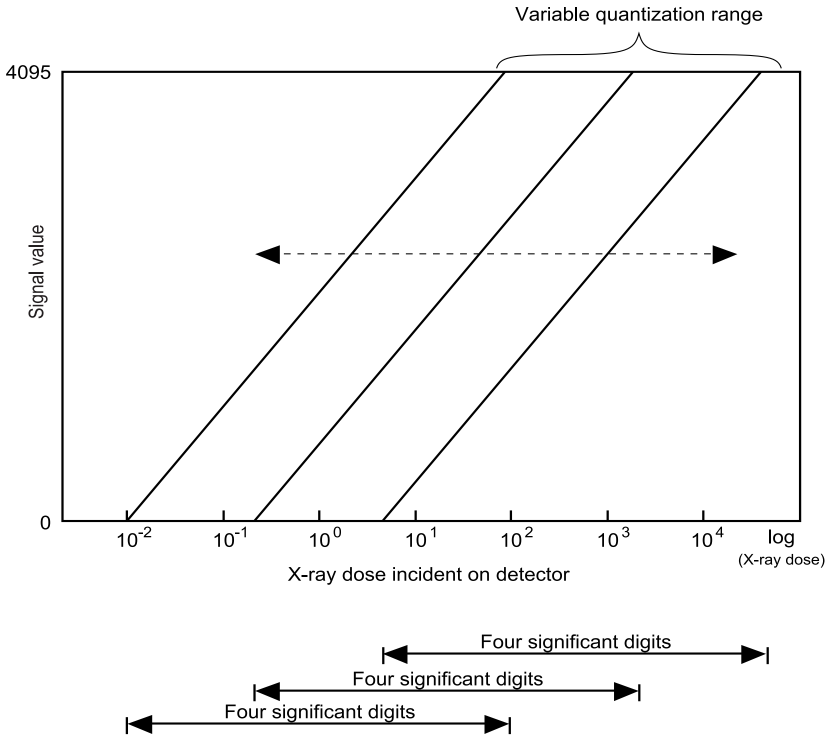


Figure 3-1-1 Quantization range and digitization range

The choice of which four digit range to digitize, is determined by the quantization range QR parameter set beforehand.
The quantization value can be chosen from three values, 125, 250, and 500, and it is independently set by the exam tag according to the method or part of exposure.

3.1.2 Quantization Range QR Parameter

The QR is the parameter that defines the REGIUS 170 quantization range. The quantization range that outputs a signal value of 1535 is defined as QR = 200 when one mR X-ray dose from a tube voltage of 80 kVp arrives at the REGIUS plate.

* 1R = 2.58 x 10^{-4} C/kg

If QR is set equal to 200, a four-digit range is digitized approximately centered on 1mR.

The following expressions show the relationship between the REGIUS digitization range and QR value.

$$\text{Digitization range } \frac{200}{QR} \times 1[mR] \times 10^{-1.5} \text{ to } \frac{200}{QR} \times 1[mR] \times 10^{2.5}$$

When QR = 125,	approximately 0.05 - 506 mR
When QR = 250,	approximately 0.025 - 250 mR
When QR = 500,	approximately 0.013 - 126 mR

For a given X-ray dose arriving at the REGIUS plate, different quantization ranges, or QR values, cause different digital output values as shown in Figure 3-1-2.

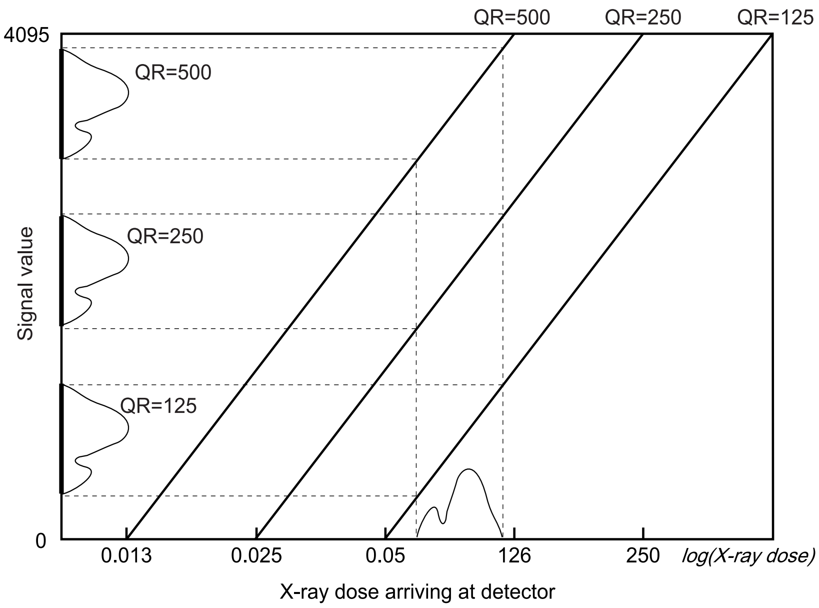


Figure 3-1-2 Quantization range QR parameter value

3.2 Pixel Size

For a given exposure size, the required spatial resolution will differ depending on the body part and diagnostic application or purpose. Furthermore, owing to different processing capacity, memory storage and network environments of computers in different facilities, it is difficult to unmistakably specify the optimum spatial resolution.

To allow optimum diagnostic images for the body part, diagnostic purpose etc. concerned, REGIUS 170 allows the pixel size (sampling pitch) to be selected from two possible sizes.
These pixel sizes may be respectively used as either "Normal Mode" or "High Resolution Mode", and can be freely switched for every exposure.

Pixel Size (µm)
87.5
175.0

Read image size (inch)
14 x 17
14 x 14
11 x 14
10 x 12
8 x 10
24 x 30 (cm)
18x24 (cm)
Mammography 24 x 30 (cm)
Mammography 18 x 24 (cm)

Table 3-2-1. Read pixel size and read image size of the REGIUS 170

3.3 Image Data Size

Table 3-3-1 shows the number of pixels and image data size for each image pixel size and exposure size.

Read image size	Pixel size (spatial resolution)	
	87.5µm(11.4 pixels/mm)	175.0µm(5.7 pixels/mm)
8" x 10"	2280x2860 12.4MB	1140x1430 3.1MB
10" x 12"	2860x3444 18.8MB	1430x1722 4.6MB
11" x 14"	3144x4020 24.1MB	1572x2010 6.0MB
14" x 14"	4020x4020 30.8MB	2010x2010 7.7MB
14" x 14"	4020x4892 37.5MB	2010x2446 9.4MB
18 x 24 (cm)	2016x2700 10.4MB	1008x1350 2.6MB
24 x 30 (cm)	2700x3384 17.4MB	1350x1692 4.4MB
Mammography 24 x 30 (cm)	2720x3388 17.6MB	–
Mammography 18 x 24 (cm)	2720x2708 10.4MB	–

Table 3-2-1. Read image size and the number of pixels for the REGIUS 170

3.4 Cycle Time

If the cassette size (read image size) or pixel size is different, the cycle time for continuous reading is different since the reading time for a cassette differs. Read cycle time for each pixel size and cassette size is shown in Table 3-4-1 (when the arrived X-ray dose at the plate is less than 40 mR). Table 3-4-2 shows processing capacity. Processing time differs if the reading and the output from the host computer or imager are conducted simultaneously.

Cassette size	Pixel size	
	87.5µm	175.0µm
8" x 10"	About 43 seconds	About 35 seconds
10" x 12"	About 47 seconds	About 37 seconds
11" x 14"	About 51 seconds	About 40 seconds
14" x 14"	About 51 seconds	About 40 seconds
14" x 17"	About 58 seconds	About 44 seconds
18 x 24 (cm)	About 41 seconds	About 34 seconds
24 x 30 (cm)	About 45 seconds	About 37 seconds
Mammography 24 x 30 (cm)	About 50 seconds	—
Mammography 18 x 24 (cm)	About 45 seconds	—

Table 3-4-1. Cycle time for each cassette size and each pixel size

Cassette size	Pixel size	
	87.5µm	175.0µm
8" x 10"	About 83 exposures/hour	About 102 exposures/hour
10" x 12"	About 76 exposures/hour	About 97 exposures/hour
11" x 14"	About 70 exposures/hour	About 90 exposures/hour
14" x 14"	About 70 exposures/hour	About 90 exposures/hour
14" x 17"	About 62 exposures/hour	About 81 exposures/hour
18 x 24 (cm)	About 87 exposures/hour	About 105 exposures/hour
24 x 30 (cm)	About 79 exposures/hour	About 97 exposures/hour
Mammography 24 x 30 (cm)	About 71 exposures/hour	—
Mammography 18 x 24 (cm)	About 80 exposures/hour	—

*1. Processing time for the first and the second cassette will be extended about 2 seconds

*2. Delete time will be extended depending on the arrived X-ray dose at the plate. If the arrived X-ray dose at the plate exceeds 240 mR, the processing time will be extended to a maximum of 31 seconds for the 14" x 17" size.

Table 3-4-2. Processing capacity for each cassette size

Chapter4

Image Processing

4.1 REGIUS Image Processing

X-ray images read by the REGIUS 170 will be transferred to the CS-1. Image processing will be conducted on the CS-1 according to the selected exam tag before exposure.

The CS-1 has five image processing capabilities: automatic gradation processing (G processing), frequency processing (F processing), equalization processing (E processing), and hybrid processing (H-F processing or H-E processing).

Of these, automatic gradation processing is indispensable for the production of images suitable for diagnostic use.

On the other hand, frequency processing, equalization processing, and hybrid processing are additional image processing depending on the body part concerned, posture, diagnostic purpose, and the request from physicians.

4.2 Automatic Gradation Processing

4.2.1 Explanation of Automatic Gradation Processing

Automatic gradation processing is a method of image processing in which the optimum gradation processing conditions are automatically determined for each separate image so that adjusting the gradation of the images in accordance with those conditions results in stable output of images with density and contrast suitable for diagnosis.
Automatic gradation processing serves two purposes as follows.

○ **It allows stable output of images to be always obtained irrespectiveof variations in patient physique or X-ray dose.**

With earlier screen/film systems deviations from the proper exposurerange (under exposure or over exposure) results in images unusable for diagnosis (Figure 4-2-1a).
On the other hand, the response from the REGIUS plate has excellent linearity in a wide range of X-ray exposures. Therefore, acquisition of image signals presents no issues even when there is some residual scatter in the band of arrived X-ray dose, which is affected by patient physics or irradiation conditions (Figure 4-2-1b).
However, in order to obtain good output images, it is necessary to compensate for the variations in the intensity of the incident X-rays so as to ensure that appropriate density and contrast are maintained at all times. For this reason for each image, the image data needs to be analyzed so that appropriate gradation processing conditions can be determined.

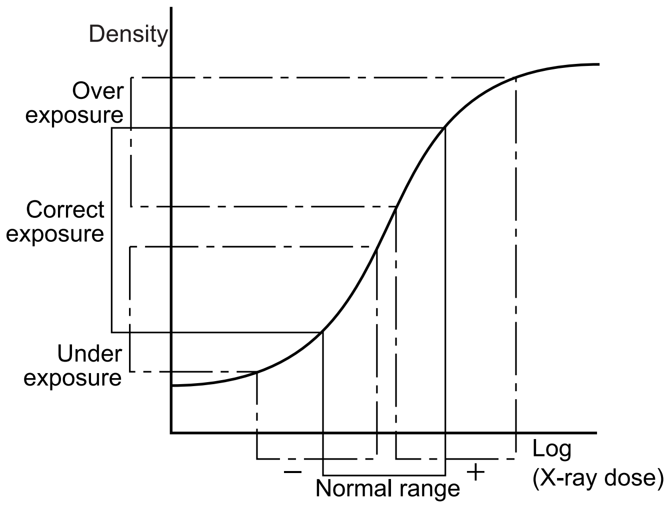


Figure 4-2-1a Density characteristics of screen/film systems

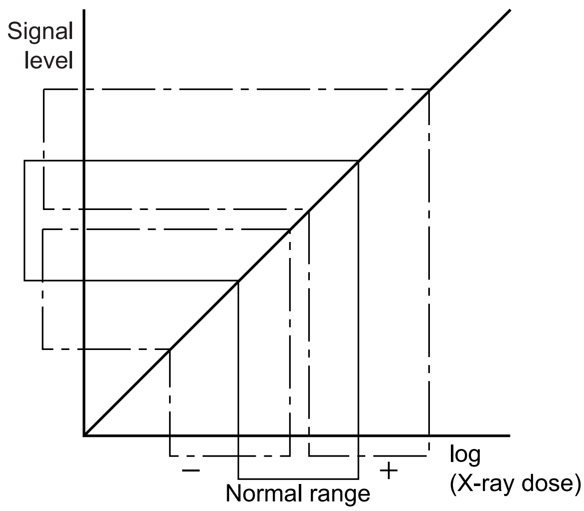


Figure 4-2-1b REGIUS signal characteristics

○ **The gradation characteristics of the image signal obtained from the REGIUS photostimulable florescent detector need to be converted to the non-linear characteristics of an X-ray image diagnostic system.**

The image signal obtained by the REGIUS plate is proportional to the logarithmic value of the arrived X-ray dose as is shown in Figure 4-2-2a.
In film terminology this is $\gamma = 1$ gradation characteristic and if this signal was to be output as is, it would result in an image which would be difficult to use for diagnosis due to insufficient overall contrast. As a countermeasure, to ensure sufficient contrast in the signal range important for diagnosis, the image signal is converted to the non-linear gradation characteristics shown in Figure 4-2-2b.

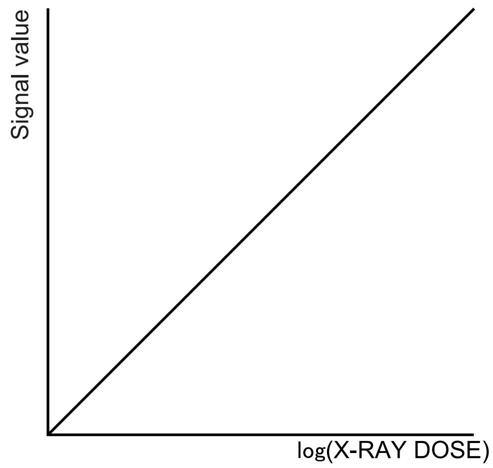


Figure 4-2-2a REGIUS signal characteristics

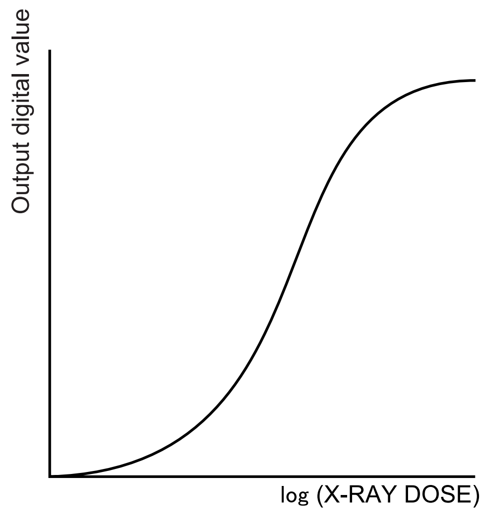


Figure 4-2-2b REGIUS signal characteristics after gradation processing

4.2.2 LUT

REGIUS automatic gradation processing converts the image signal using a LUT (Look Up Table) whose input and output signals have a relationship similar to that shown in Figure 4-2-3.
As can be seen from the figure, the LUT has a characteristic curve resembling those of screen and film systems.
To allow appropriate automatic gradation processing to be performed for a wide variety of exam body parts and physiques, REGIUS has been provided with Look Up Tables with various curve shapes.

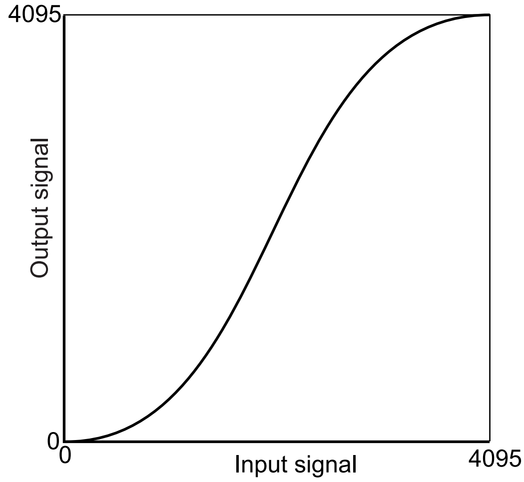


Figure 4-2-3 CS-1 LUT example

4.2.3 Automatic Gradation Processing Algorithm

Figure 4-2-4 shows a flow diagram for REGIUS automatic gradation processing.

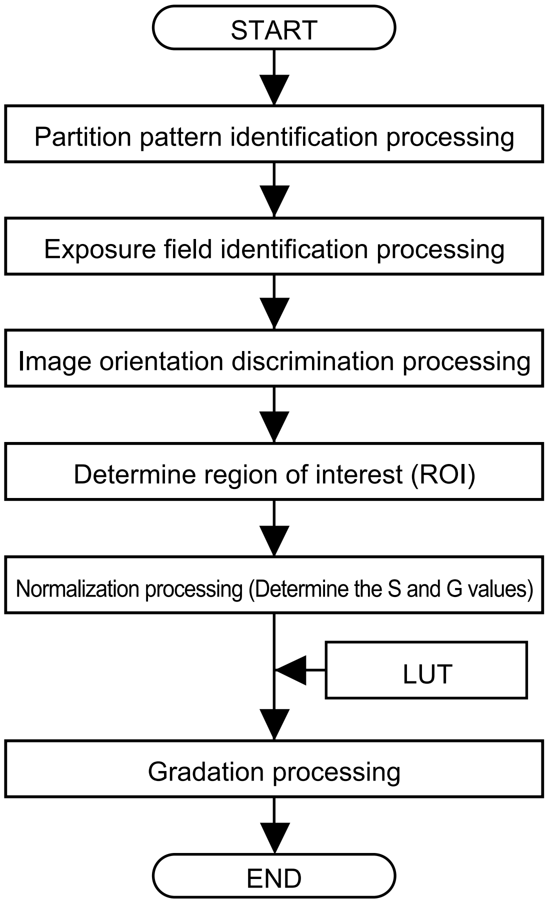


Figure 4-2-4 Flow diagram for automatic gradation processing

In the REGIUS, even after automatic processing, the raw image data (unprocessed image data) and the image processing parameters (normalization processing parameters and LUT parameters) are stored separately. This means that processing can be repeated as often as desired with different image processing parameters.

Furthermore, the raw image data, image processing parameters, and processed image data etc., can be flexibly output to other environments.(Refer to "6.2.1 Online Output Functions")

■ Partition Pattern Identification Processing

Partition pattern identification processing determines whether or not partition exposure has been performed and identifies the sizes and distribution of the partition areas when partition exposure has been performed. Partition pattern identification processing allows each partition area to be handled as a single image area and so makes possible stable processing which is not affected by signals from areas that have not been exposed or that have suffered double exposure. The partition area patterns that can be identified with partition pattern identification processing are as shown below.

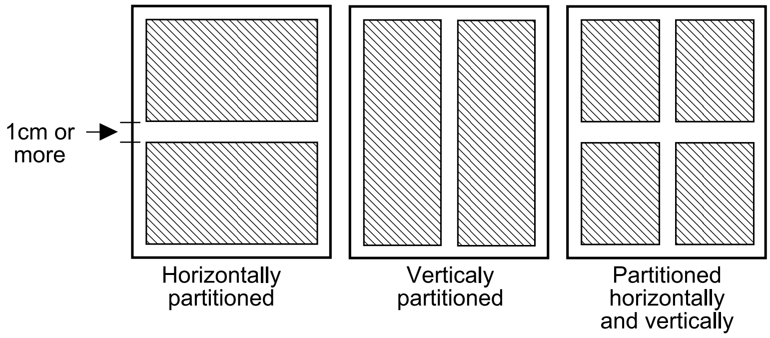


Figure 4-2-5 Partition patterns that can be identified

As shown in Figure 4-2-6, partition pattern identification processing is performed by detecting large changes of signal value in the central area.

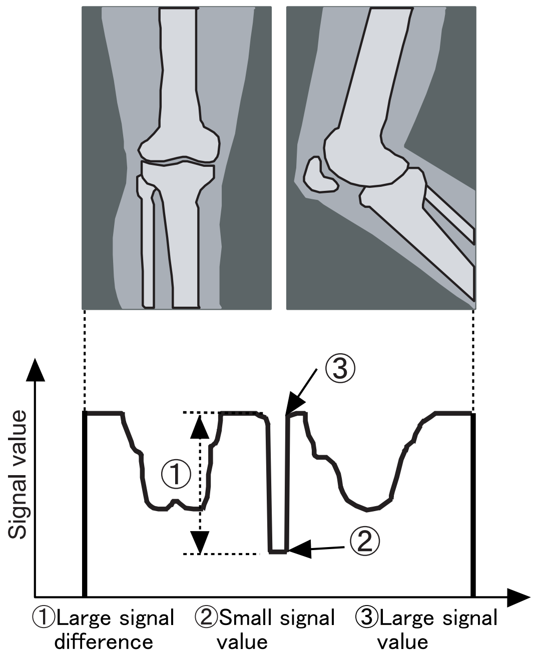


Figure 4-2-6 Signal value changes of partition exposure image

① Straight line of large differences between signal values of neighboring pixels. (Partition boundary line edge)

② Straight line of small signal values (Unexposed area)

③ Straight line of large signal values (Area of double exposure or of exposure to direct radiation)

* However, applicable parts are limited to the following.

•Head

•Hand and arm at the end of the humerus

•Foot and leg at the end of the femur

■ Exposure Field Identification

Exposure field identification is the processing that extracts and defines the range of exposure from the whole image data obtained by the plate. In the case of separate exposures, the identification is made using image data from the separate regions. The purpose of exposure field identification is to avoid the adverse effect of the signal for regions outside the exposure field that are not needed for diagnosis,

in the determination of the image processing conditions to be used for automatic gradation processing.

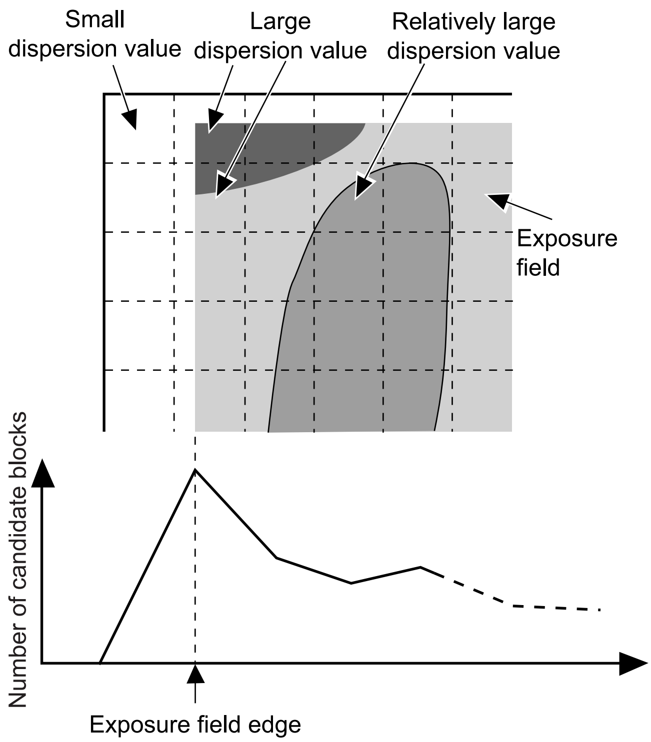


Figure 4-2-7 Exposure field identification

(1) Divide the image into small blocks and compute a dispersion value for each block.

(2) Blocks containing the edges etc. of the exposure field will have large dispersion values. Use this Characteristic to select blocks with large dispersions as candidate blocks.

(3) Find areas in which many candidate blocks form a straight line and take this to be an exposure field boundary.

(4) Take the rectangular area surrounded by the exposure field boundaries as the exposure field.

REGIUS has a number of different exposure field identification algorithms and chooses which one to use depending on the body part selected with the exam tag.

For further details about the types of REGIUS exposure field identification, please refer to "CS-1 Exposure Field Identification Type" at the end of this chapter.

■ Image Orientation Discrimination Processing

Image orientation discrimination processing determines the orientation of the body part in the image and rotates the entire image as required by circumstances.
For example, if exposure is performed with the cassette horizontal as shown in Figure 4-2-8b, the orientation of the body within the image read by REGIUS 170 will be horizontal. This will be automatically detected, and the image will be rotated.

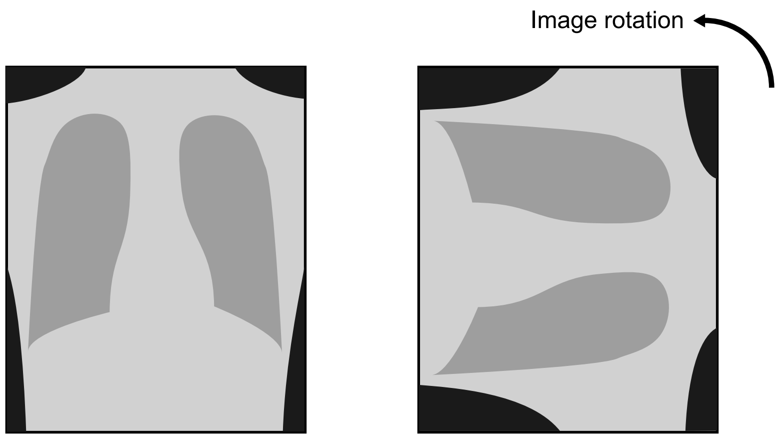


Figure 4-2-8a Vertical exposure **Figure 4-2-8b Horizontal exposure**

As a result, images are displayed on the CS-1 console panel or external devices so that the parts nearer the head appear at the top. Thus, inspection of the image and diagnosis can be conducted more conveniently.
Discrimination of subject orientation is performed by dividing the image into nine blocks as shown in Figure 4-2-9 and comparing the typical value for each of the shaded blocks determined by statistical methods.

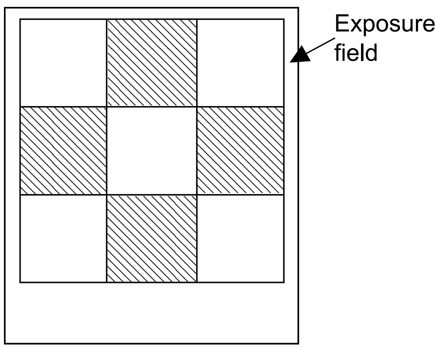


Figure 4-2-9 Blocks used for image orientation discrimination processing

* However, this processing is limited to the following body parts:
- Chest PA/AP
- LAT chest
- New born/PED chest and abdomen
- Abdomen PA/AP
- Pelvis PA/AP
- Both hip joints

■ Setting the Region of Interest (ROI)

After identifying the exposure field, REGIUS analyses the image data within the field and determines the region of interest (ROI).
To ensure that the region of interest (ROI) matches the body part to be observed, REGIUS selects an ROI identification algorithm according to the body part to be examined and patient physique.

For further details about the ROI identification algorithms used by the REGIUS, please refer to "CS-1 ROI Setup Algorithms" at the end of this chapter.

The different types of regions of interest (ROI) can be generally classified into two groups, each of which uses a different algorithm. Of the types shown in the table at the end of this chapter, types A to O other than M and N use algorithm (a) while types M and N use algorithm (b) as described below.

(a)Automatic extraction of a specific human anatomical structure.

(b)Selects a given area within the exposure field.

■ Setting Reference Signal Values

REGIUS analyzes the image data within the region of interest and determines one or two reference signal values.

If a chest PA/AP image is taken as an example, the maximum signal value for the lung area (H reference value) and the minimum signal value for the mediastinum area (L reference value) are selected as indices for densities in the final image. This allows achievement of densities considered desirable for the body part concerned.

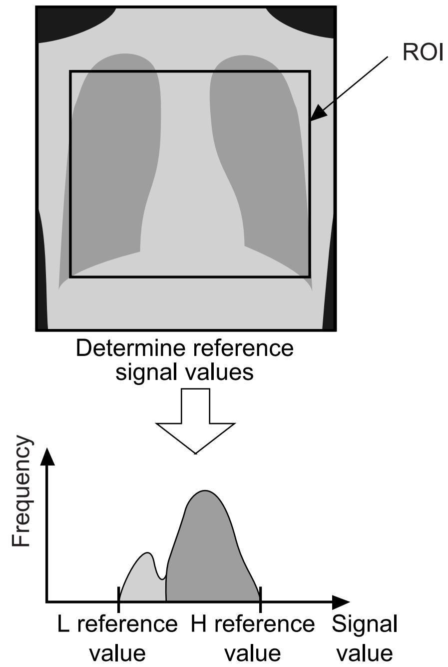
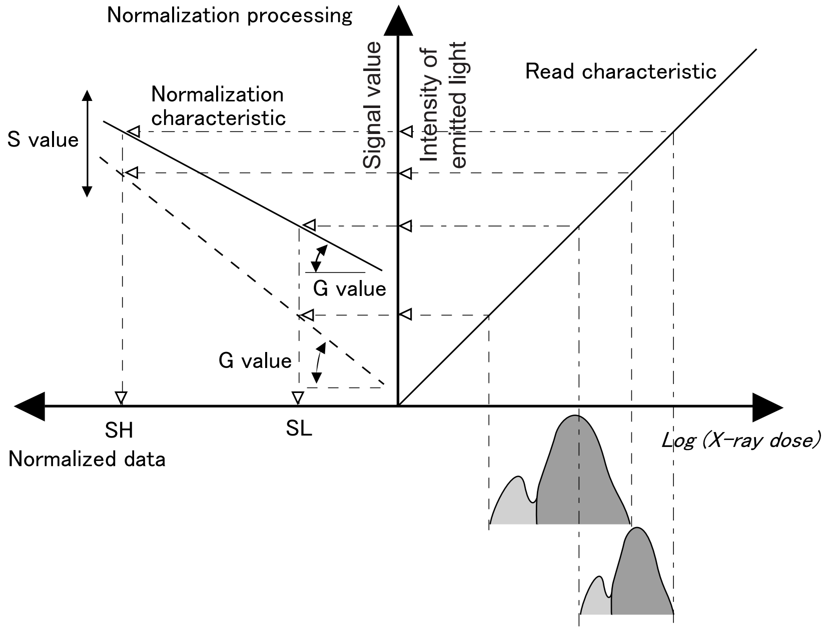


Figure 4-2-10 Setting reference signal values (chest PA/AP example)

The reference section "REGIUS ROI Setup Algorithms" at the end of this chapter, shows for each ROI type, reference signal values suitable for the body parts within the ROI. These were found through statistical analysis.

■ Normalization Processing

Normalization processing is used to correct for variations in incident Xray dose due to variations in patient physique or X-ray exposure conditions etc. To ensure that the reference signal values determined by the "■ Setting Reference Signal Values" match the signal values (SL, SH) determined previously, the image processing parameters (G value: contrast value, S value: density correction) are determined (calculated) and are then used to process (normalize) the image data.



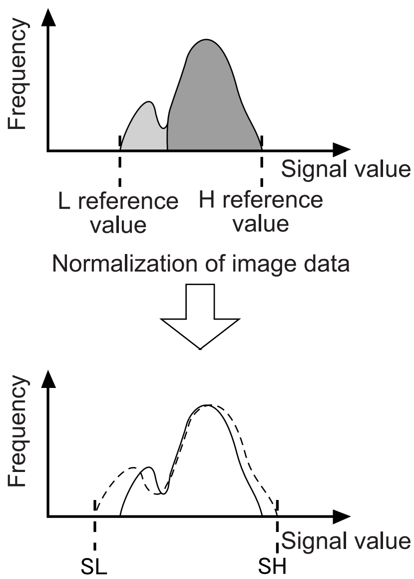


Figure 4-2-11 Normalization of image data

As shown in the top graph in Figure 4-2-11, changing the value of G (the slope of the normalization characteristic) changes the range of the image data signal value which changes the contrast of the image. On the other hand, changing the value of S (the y intercept of the normalization characteristic) increases or decreases the image data signal value which changes the density of the image.

From the next page, we will discuss the concept of the S and G parameters via comparison with the characteristics of screen/film systems.

G Value

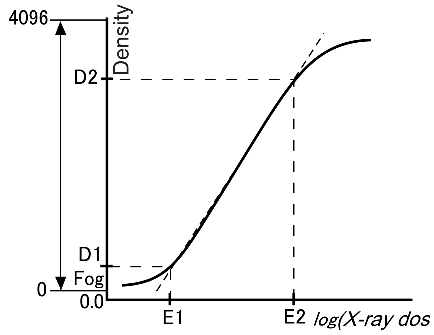
Figure 4-2-12 shows an example in which two patients A and B of differing physique are X-rayed onto a film with characteristic (1). In this example patient A has a normal physique, while patient B is heavy and obese.

If a film with characteristic (1) is used for both patients, then because, for patient B, the X-ray dose that arrives at the film will have a greater range, the image produced for B will have greater range of density than that produced for A. If we wish to produce an image for B with the range of densities as that for A, then we need to use a film with a wider latitude such as shown by characteristic (2). With REGIUS, in the case of patient A, performing gradation processing with a LUT with the same characteristics as the film characteristic (1) would allow production of an image identical to that produced with the film. Furthermore, in the case of patient B, changing the G value of the normalization characteristic shown in Figure 4-2-11, would allow production of an image of equivalent range of density to that produced for patient A, using the same LUT as used for patient A.

G Value:

The value of G is given by the following equation for the characteristic curve.

$$G=\frac{D2-D1}{LogE2-LogE1} \quad \left[\begin{array}{l} D1 = 0.25 + Fog \\ D2 = 2.0 + Fog \\ Fog = 0.2 \end{array}\right]$$



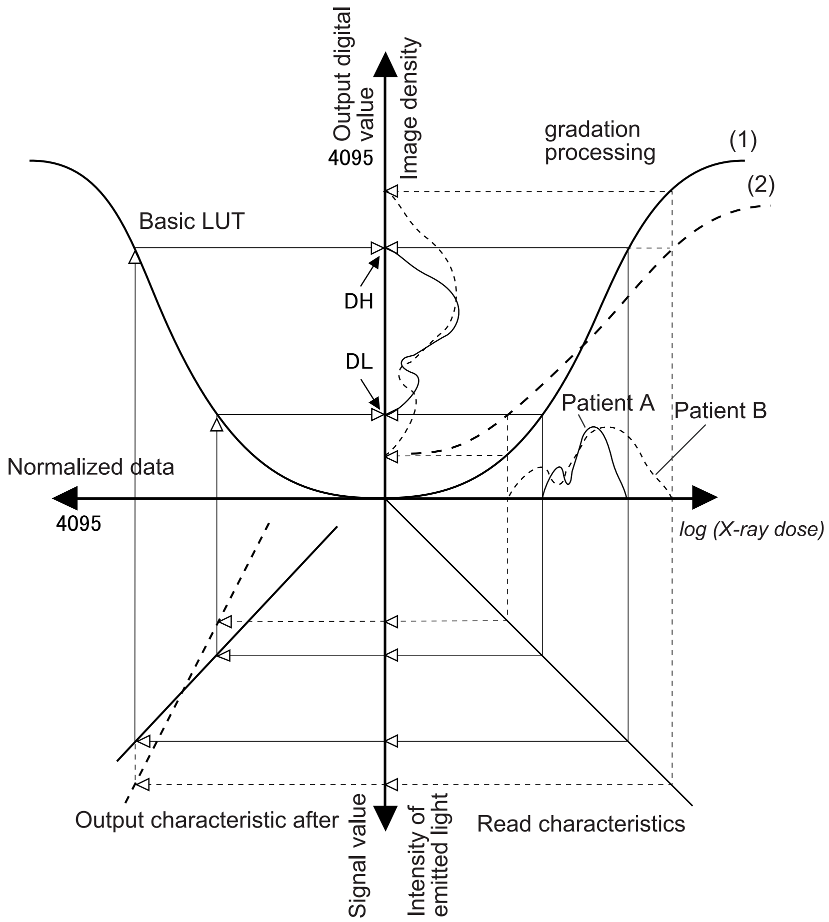


Figure 4-2-12 G value and film contrast

Accordingly, when the patient is X-rayed under particular exposure conditions, the G value indicates the contrast of the output image produced by normalization processing. This is equivalent to the film γ required to produce the contrast between the reference signal values set with densities DL and DH.

S Value

Figure 4-2-13 shows an example in which two patients A and B of identical physique are X-rayed with differing doses, onto a film with characteristic (1).

As the film with characteristic (1) is used for both, and patient B is subjected to a higher X-ray dose than A, the image produced for B is denser than that produced for A. Furthermore, because the useful density range of the film is exceeded, the contrast is reduced, making the image unsuitable for diagnosis. If you wish to produce an image for B with the same density as that of A but using a higher dose, then we need to use a film with the same gamma value but with lower sensitivity such as shown by characteristic (2). With REGIUS, in the case of patient A, performing gradation processing with an LUT with the same characteristics as film characteristic (1) would allow production of an image identical to that produced with the film. Furthermore, in the case of patient B, changing the S value of the normalization characteristic shown in Figure 4-2-11, would allow production of an image equivalent to that produced for patient A, using the same LUT as used for patient A.

S Value:

Let QR be the range of the quantization region. Let R be the incident X-ray dose on the detector that produces a signal value of 1535. (reading with QR of 200 when fixed processing produce an output density of 1.2) Let R' be the actual X-ray dose required to produce a film output density of 1.2 at a pixel following gradation processing. Then S is defined as:

$$S = QR \times \frac{R}{R'}$$

The value of R is uniquely determined by the quantization region QR parameter set before exposure.

QR	R(mR)
125	1.6
(200)	1
250	0.8
500	0.4

If the same subject is exposed using the same Xray characteristics, same positioning and same exam tags, a doubling of the X-ray dose will halve the S value.

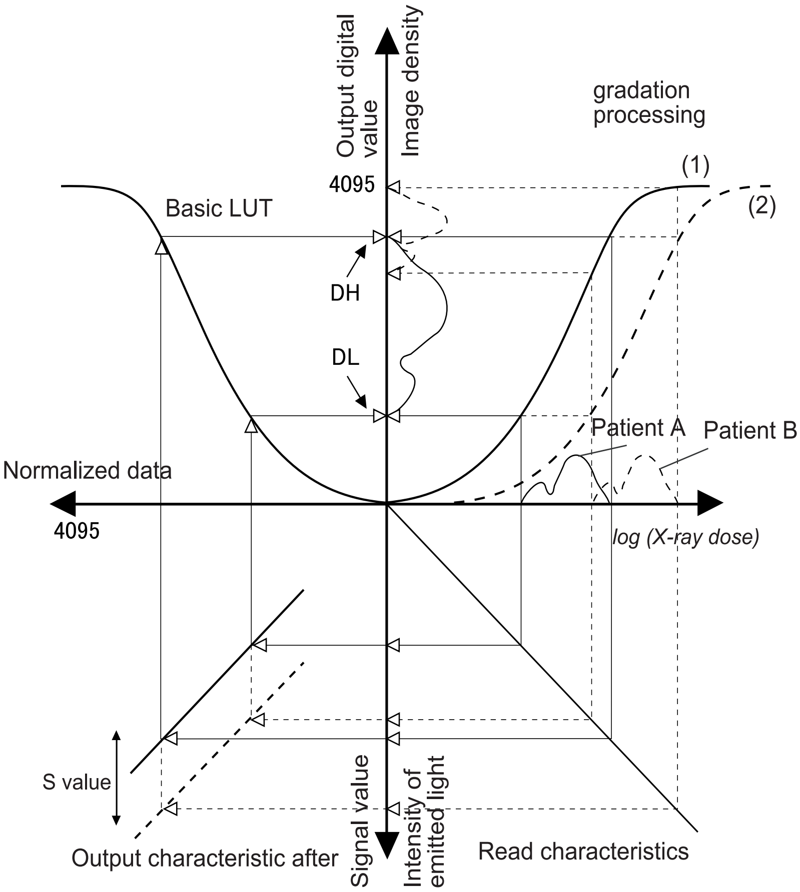


Figure 4-2-13 S value and film image density

Accordingly, when the patient is X-rayed under particular exposure conditions, the S value corresponds to the density of the output image produced by normalization processing. This is equivalent to the film sensitivity required to produce a density between the reference signal values set with densities DL and DH.

For example, if the chest is X-rayed with a film with a characteristic slope equal to the G value, then to produce an image in which the density of the mediastinum area is L and the higher density of the lung area is H, the sensitivity of the film needs to be S.

■ Gradation Processing

The image data that has been normalized according to the S and G values, is subjected to gradation processing based on a pre-determined LUT so as to produce an image (output signal value) with the desired gradation.

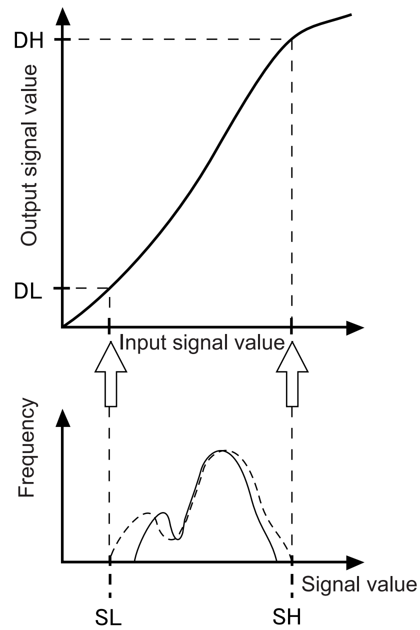


Figure 4-2-14 Gradation processing using an LUT

As explained earlier in "4.2.2 LUT", the LUT has a characteristic curve that resembles that of screen/film systems so the output image is compatible with the output images produced by existing screen/film systems.

Figure 4-2-15 shows the relationship between REGIUS gradation processing parameters and the output characteristics.

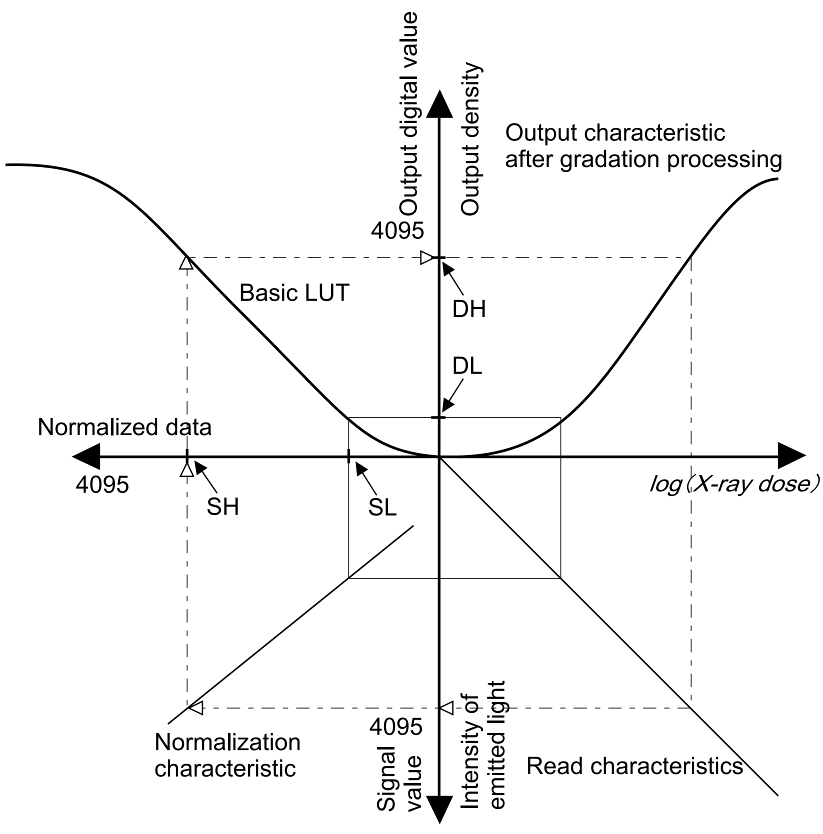


Figure 4-2-15 Gradation processing parameters and output characteristics

4.2.4 Correcting Image Processing Parameters

REGIUS has "image processing parameter edit" functions that allow the image processing parameters used with previously acquired images to be edited.

If the wrong exam tag has been selected or if the desired result is not achieved in the following automatic gradation processing or if you wish to apply a form of image processing that differs from the normal processing, you can freely change the image processing without the need to repeat the exposure.

Image processing parameters can be revised by changing the previously mentioned image processing parameters (ROI range, S value, G value, and applicable LUT) on the CS-1 console panel.

4.3 Frequency Processing

4.3.1 Explanation of Frequency Processing

Frequency processing is a form of image processing which modifies image spatial frequency characteristics, so that structures of body parts are displayed more sharply.

Spatial Frequency:
Spatial frequency is an index that expresses the degree of detail in a structure. For example if an image signal value had a repetitive pattern that varied sinusoidally in the form large → small → large → small..., the spatial frequency would be the number of such cycles repeated within a length of one millimeter. This would be expressed in units of "c/mm" or "lp/mm". While a coarsely repetitive pattern has a low spatial frequency, a fine pattern has a high frequency

Since the spatial frequency components of an actual X-ray image are composed of patterns of various frequency, we can draw a graph in which spatial frequency is plotted along the horizontal axis, and signal strength (intensity) along the vertical axis. Doing this will generally result in a graph as shown in Figure 4-3-1.

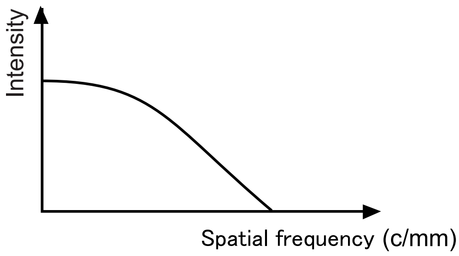


Figure 4-3-1 Example of X-ray image spatial frequency characteristics

4.3.2 Frequency Processing Algorithm

The REGIUS spatial frequency processing uses a simple high speed processing method known as "smoothing mask processing.

"Smoothing mask processing applies the following computations to the image data.

S = Sorg + β (Sorg - Sus)

S	:Frequency processed image signal
Sorg	:Original image signal
Sus	:Smoothed image signal
β	:Emphasis coefficient

First, a smoothed image signal (Sus) is derived from the original image to which one wishes to apply frequency processing as follows.

(1) As shown in Figure 4-3-2, a square mask with sides of length (2N + 1) is centered over the pixel to be processed.

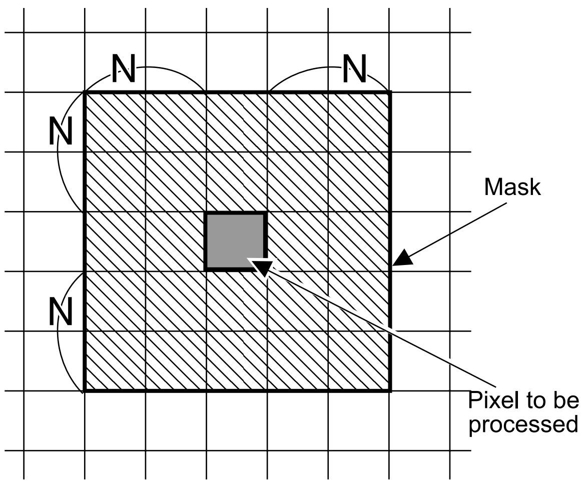


Figure 4-3-2 Deriving a smoothed image

(2) The average value of the pixels within the mask is calculated and assigned to the central pixel as its smoothed image signal.
(3) Moving the mask one pixel at a time, step (2) is repeated for each pixel, so as to obtain the smoothed image signal for all pixels in the image.

The smoothed image obtained as a result of the above processing has a blurred appearance compared to the original image (Figure 4-3-3a, Figure 4-3-3b).

Next, for all pixels, the difference between the original image and the smoothed image, (Sorg - Sus) is computed. The image obtained as a result of this computation is equivalent to an image created by extracting from the original image, high frequency components of frequency higher than a certain value (Figure 4-3-3c).

Finally (Sorg-Sus) multiplied by emphasis coefficient β, is added to the original image (Sorg). This produces the frequency processed image (S) (Figure 4-3-3d).

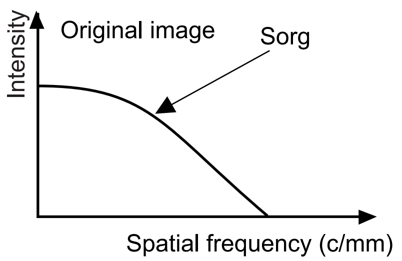


Figure 4-3-3a

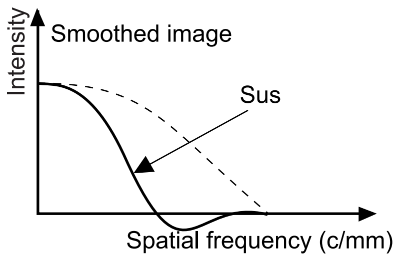


Figure 4-3-3b

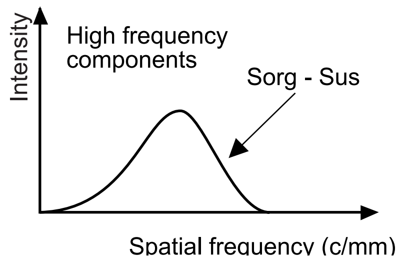


Figure 4-3-3c

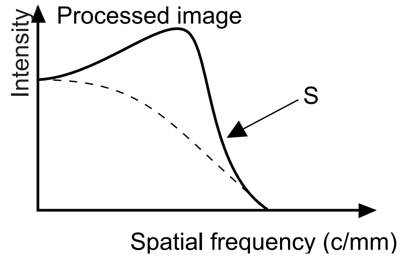


Figure 4-3-3d

Figures 4-3-4a to Figure 4-3-4d below show the stages of frequency processing using a simple step pattern as an example.

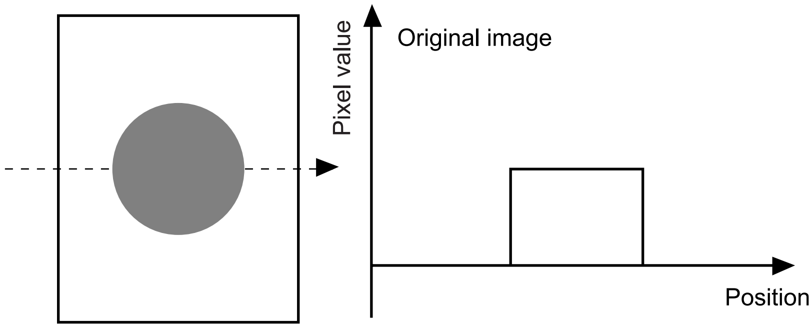


Figure 4-3-4a

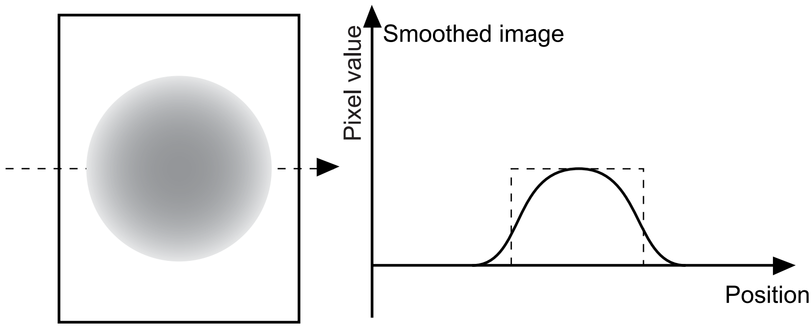


Figure 4-3-4b

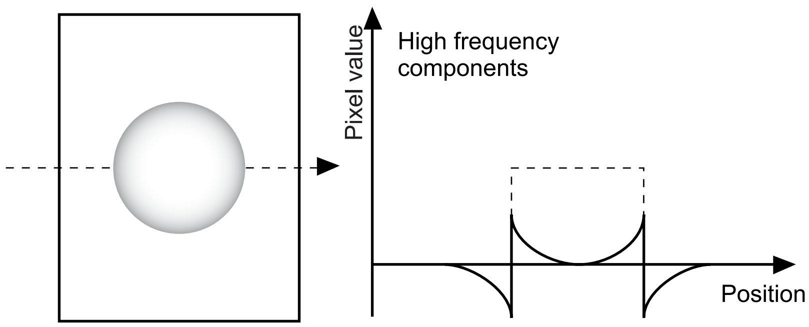


Figure 4-3-4c

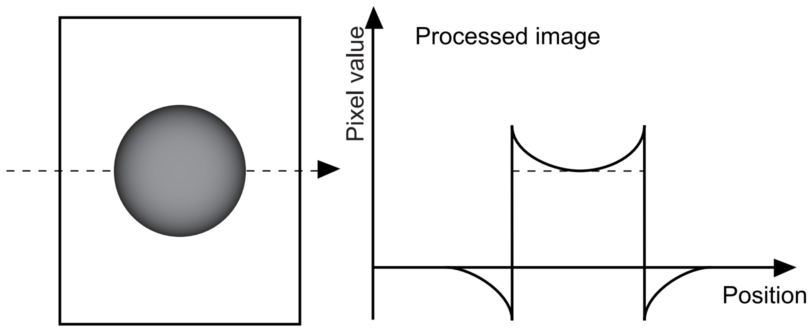


Figure 4-3-4d

4.3.3 Frequency Processing Parameters

In frequency processing, the "mask parameter" and "emphasis coefficient" are important parameters.
The mask parameter is concerned with the size of the mask used to produce the smoothed image. The larger the mask parameter, the lower the spatial frequency that will be most emphasized.
Accordingly, the larger the mask used for frequency processing, the more blurred will be the smoothed image, and the right shoulder of the spatial frequency characteristic of the smoothed image signal will droop more steeply (Figure 4-3-5a). As a result, the peak frequency used for emphasis will be moved to a lower frequency (Figure 4-3-5b).

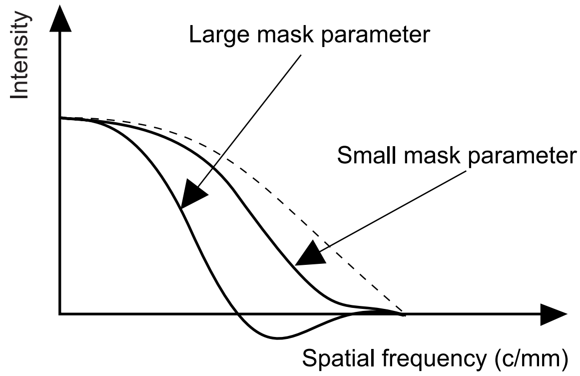


Figure 4-3-5a Mask parameter and smoothed image

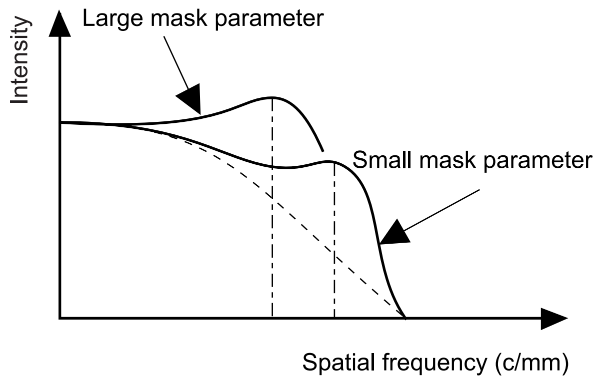


Figure 4-3-5b Mask parameter and frequency processed image

In REGUIS the mask parameter is defined as "the value for N in Figure 4-3-2 when the read pixel size is 175µm".
When processing an image with pixels of size other than 175µm, the number pixels along one side of the mask will differ from this, but the physical size of the mask will be maintained unchanged.
For example, if the mask parameter has a value of 5 and the pixel size is 175µm, the mask will be computed as 11 pixels x 11 pixels (2N + 1), but if the pixel size is 87.5µm the mask will be computed as 21 pixels x 21 pixels (4N + 1). However, in both cases the physical mask size on the image will be about 2mm square so the peak frequency for emphasis (c/mm) will not change.
Figure 4-3-6 shows the relationship between the mask parameter and the peak frequency for emphasis.

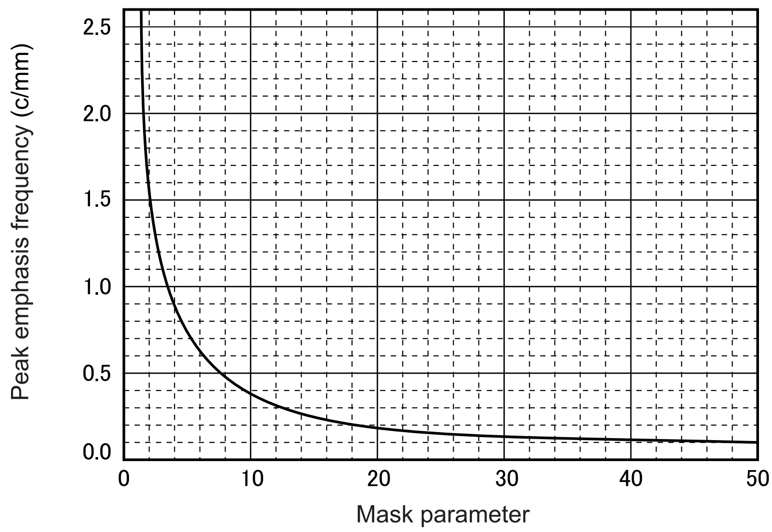


Figure 4-3-6 Mask parameter and emphasis frequency

4.3.4 Frequency Processing Parameters (right shoulder rising)

The emphasis coefficient β is the parameter that determines the degree of frequency emphasis, so the larger the emphasis coefficient the greater the degree of emphasis.
However, if the emphasis coefficient is made large, the sharpness of the image is increased, but X-ray noise etc. is also emphasized and this may lead to observable speckling. For this reason, instead of keeping the emphasis coefficient β fixed, it is made to vary with density as shown in Figure 4-3-7. Small values of a are thus used for low densities where speckling tends to be noticeable, and larger values for higher densities where speckling is less noticeable. Furthermore, if the emphasis coefficient is made too large, this may make an unnatural image that looks different from the one on the traditional screen/film.

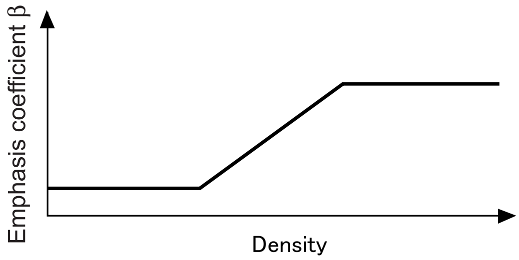


Figure 4-3-7 Emphasis coefficient β and density

Table 4-3-1 and Table 4-3-2 show two sets of representative frequency processing parameter settings.
•Light Frequency Processing

Processing name		Chest simple	Abdomen simple	Extremities (parts containing small bones)	Pelvis PA/AP etc. (parts containing large bones)
Mask parameter		7	16	3	3
Emphasis coefficient β	Low density areas (lowest value)	0.0	0.0	0.0	0.0
	High density areas (highest value)	0.3	0.3	0.3	0.3

Table 4-3-1 Light frequency processing parameter settings

•Heavy Frequency Processing

Processing name		Chest simple	Abdomen simple	Extremities (parts containing small bones)	Pelvis PA/AP etc. (parts containing large bones)
Mask parameter		11	16	12	8
Emphasis coefficient β	Low density areas (lowest value)	0.0	0.0	0.0	0.0
	High density areas (highest value)	3.0	3.0	3.0	3.0

Table 4-3-2 Heavy frequency processing parameter settings

4.4 Equalization Processing

4.4.1 Explanation of Equalization Processing

During equalization processing, the dynamic range of an image signal based on a smooth image signal is reduced. This allows an image with a wide dynamic range to be converted to one with a smaller dynamic range which is easier to view.

In general, when an X-ray image is used for diagnosis, the image will contain an area of primary interest and an area of secondary interest. For example in chest PA/AP images the lung is of primary interest and the mediastinum of secondary interest. In this case, to display the lung area with good contrast the LUT needs to be set so that during gradation processing the medium to high signal levels are given a steep gradient.
However, if this is done, the mediastinum area which gives rise to a low signal level, is at the base of the characteristic curve (where the gradient is shallow) resulting in low contrast for this area.

Accordingly, for body parts with a wide dynamic range, it is difficult to ensure good contrast for both the area of primary interest and the area of secondary interest, and even the CS-1 would be unable to avoid this problem if it were to rely on gradation processing alone.

In this situation, equalization processing is used to bring the average density of the area of secondary interest close to that of the area of primary interest. This is similar to the role of sensitivity compensation filters used in screen/film systems.
During equalization processing, compensation is applied to broad changes of the image signal based on the smoothed image signal of the original image, so that depictions of fine signal changes (due to structures such as bone edges etc.) within the secondary area of interest are preserved.

4.4.2 Equalization Processing Algorithm

Equalization processing applies computations to the image as given by the following expressions.

$$S = Sorg + f(Sus)$$

$$f(Sus) = \beta(A - Sus)$$

However, $\beta = \beta L$ ($Sus \leqq A$)

βH ($Sus > A$)

S	: Image signal after equalization processing
Sorg	: Original image signal
Sus	: Smoothed image signal
βL, βH	: Correction coefficients
A	: Constant

If compensation is applied to all signal values below a particular signal value (intensity) as a boundary, constant A is set equal to the boundary signal level, and βL is set equal to the correct value and βH to zero.
For this case, the relation between the correction signal (f) and the smoothed image signal (Sus) is shown in Figure 4-4-1.

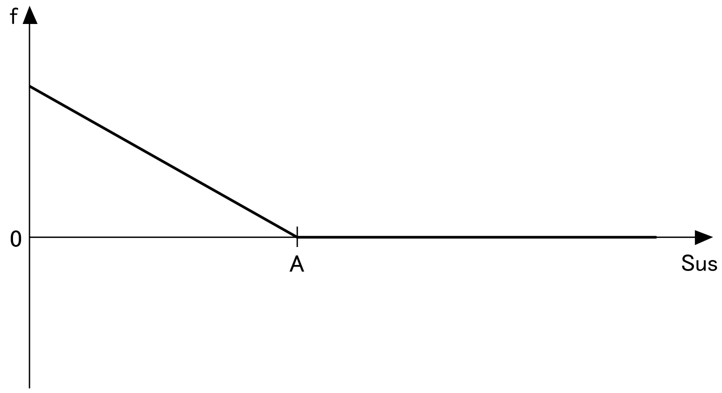


Figure 4-4-1 Correction signal example (βL > 0, βH = 0)

The following explains the principles of equalization processing using a chest PA/AP image as an example.

(1) A smoothed image (Sus) is derived from the original image (Sorg) using the same method used in frequency processing.

(2) A correction function β (A - Sus) is sought.
Here, the aim is to compensate the mediastinum area signal without changing the appearance of the lung area, so the correction function shown in Figure 4-4-1 is applied.
The value of constant A will be set, for example, to the midpoint (50%) between the maximum value of the signal for the lung area and the minimum value of the signal for the mediastinum area.

(3) Adding the correction signal (f) to the original image signal (Sorg), will produce an equalization-processed image (S).
If the pixel values along a horizontal line through the image are graphed as shown in Figure 4-4-2a, it will be seen that in the frequency processed graph (Figure 4-4-2c), the average density for the mediastinum area has been increased so that it has been brought closer to the average density for the lung area, but that the local signal changes for bone edges and blood vessels within the mediastinum area have been preserved. This is because only low frequency components were used when the correction function was determined.

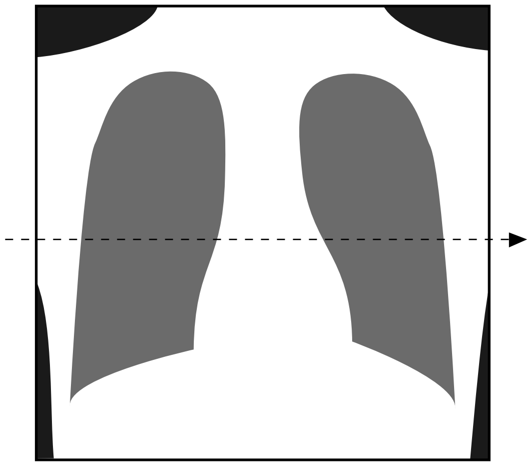


Figure 4-4-2a

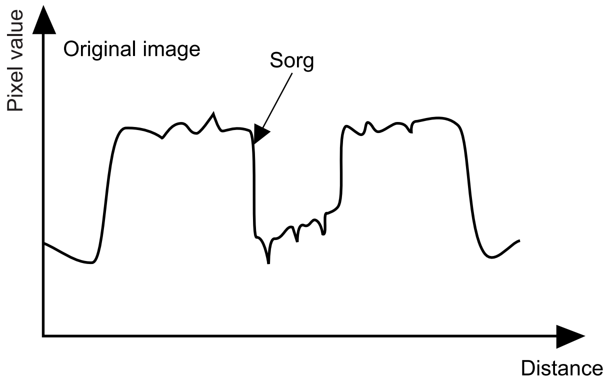


Figure 4-4-2b

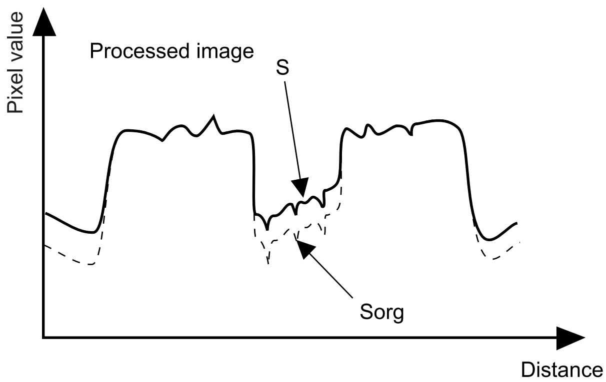


Figure 4-4-2c

4.4.3 Equalization Processing Parameters

The equalization processing parameters are, the "mask parameter", "correction coefficient" and "reference % value".

The mask parameter is specified in the same way as for frequency processing, and corresponds to the size of the mask used to produce the smoothed image. When the mask parameter is made larger, the spatial frequency limit of the spatial frequency area added for correction will be made lower. Conversely, when the mask parameter is made smaller, the effect of correction will extend to relatively higher frequencies, and may affect the contrast of ribs etc.

The correction coefficient β is the parameter that determines the degree of correction, and is usually set between 0 and 1. When the correction coefficient is made larger, the average density of the secondary area of interest becomes more even, producing an image with a flatter appearance. The reference % value is the parameter which determines the signal value A, which forms the boundary between the signal range to which correction is added, and the signal range to which no correction is made. For example, in the case of chest PA/AP, if we refer to the two reference signal values found during automatic gradation processing described earlier as reference signal L and reference signal H, then A is given by,

A = [reference signal L] + ([reference signal H] - [reference signal L]) x [reference % value]/100

Furthermore, when only one reference signal exists as in the case of LAT lumbar vertebra, if we refer to the reference signal value (the signal value for the lumbar vertebra) as L, and the maximum signal value for the body as H, then A is found using the same calculation.
Table 4-4-1 shows representative equalization processing parameter settings.

Processing name	Chest PA/AP	LAT lumbar vertebra
Mask parameter	63	95
Correction coefficient	0.3	0.4
Reference % value	50	0

Table 4-4-1 Representative equalization processing parameter settings

4.5 Hybrid Processing

4.5.1 Explanation of Hybrid Processing

Hybrid processing (H processing) is a new method of frequency processing that uses the resolution of the image in multi resolution space, and replaces the conventional method. Hybrid processing has functions of H-F processing, which adjusts the sharpness of the image, and H-E processing, which compresses the dynamic range.

■ Features of H processing

① Adjusting the sharpness depending on the parts and diagnostic purpose: The conventional method only emphasizes the frequency that is most worthy of observation. But, H processing makes sufficient intensification possible from low frequency to high frequency, the former is from the soft parts or internal organs, and the latter is from bone trabeculae or blood capillaries.
② Enabling the diagnosis of the whole structure of the human body: In the conventional method, overshooting or undershooting sometimes occurred in a high contrast area like artificial bone. H processing thus improves the overshooting and undershooting found in the conventional method.
③ Compatibility of the image granularity control and intensification of human parts by frequency processing: The conventional method slightly emphasizes the intensity in the low intensity zone in order to cope with the degradation of image granularity due to frequency processing. But, H processing is compatible with granularity control and frequency processing.

4.5.2 H-F PROCESSING

■ H-F processing Algorithm

Multiple images with reduced sharpness will be created from the original image. Next, they will be converted to intensity-dependent low sharpness images depending on the intensity. Then, each frequency component will be extracted by taking the difference of neighboring frequency bands. The extracted differential image will be added to the original image obtaining the intensified image for H-F processing.

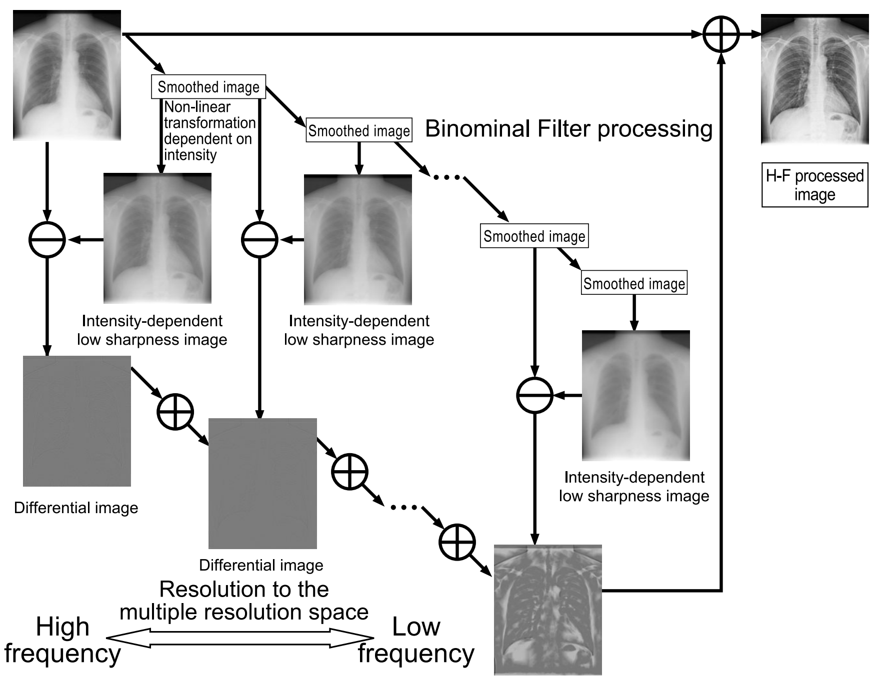


Figure 4-5-1. Algorithm of H-F processing

■ H-F processing procedures

H-F parameters (intensified band)

There are six kinds of H-F parameters from HF-standard 1 to HF-standard 6, and they are used according to the size of the object to be emphasized.

H-F TYPE	Major applicable area	Explanation
HF-STANDARD1 HF-STANDARD2	Abdomen Pelvis and other areas	Emphasizes the internal organs and soft organs and is effective for increasing the contrast for a whole image
HF-STANDARD3 HF-STANDARD4	Vertebrae (backbone) of the hip joint Femur, lower leg bone, etc.	Effective in parts like the vertebrae where large bones, bone beams, and soft parts should be emphasized. Relatively general frequency characteristics.
HF-STANDARD5 HF-STANDARD6	Limb bones, cervical vertebrae(bone beams) Chest (blood vessels), head	Effective in parts like the bone beams or blood vessels where small structures or small parts should be emphasized.

Table 4-5-1. H-F type and its applicable parts

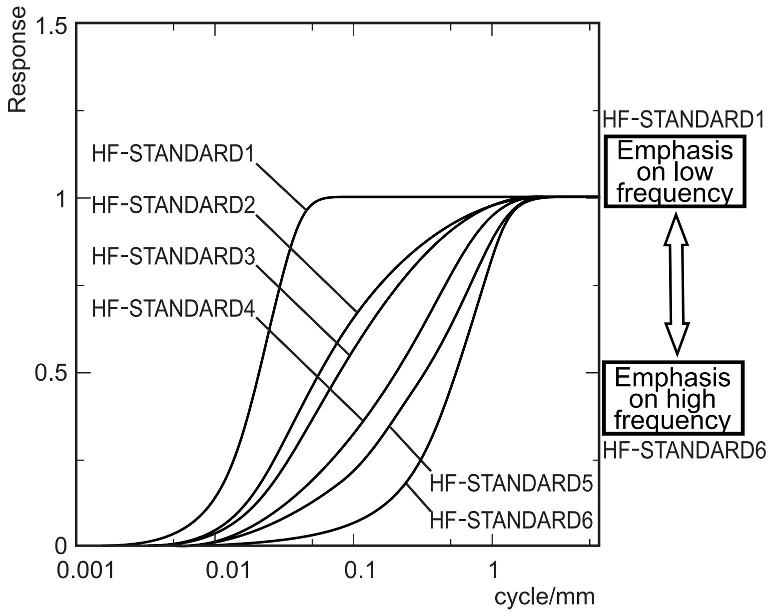


Figure 4-5-1. H-F parameters

■ H processing adjustments

Contrast can be added to the image due to the strong intensification including low frequency. Therefore, lower LUT than usual can be used, and it can stabilize the degradation.

- ○ All the parts of human body can be diagnosed by controlling the degradation granularity.
- ○ Multiple uses of H-E processing can be avoided making more natural processing possible.

4.5.3 H-E PROCESSING

■ Algorithm for H-E processing

Multiple images with reduced sharpness will be created from the original image. Next, they will be converted to intensity-dependent low sharpness images depending on the intensity. Then, each frequency component will be extracted by taking the difference of neighboring frequency bands. (It is the same as H-F processing.) Extracted differential images are added, and it is subtracted from the original image in order to obtain low frequency components. Then, compensation for intensity is performed, and the image is added to the original image. This is the image obtained by H-E processing.

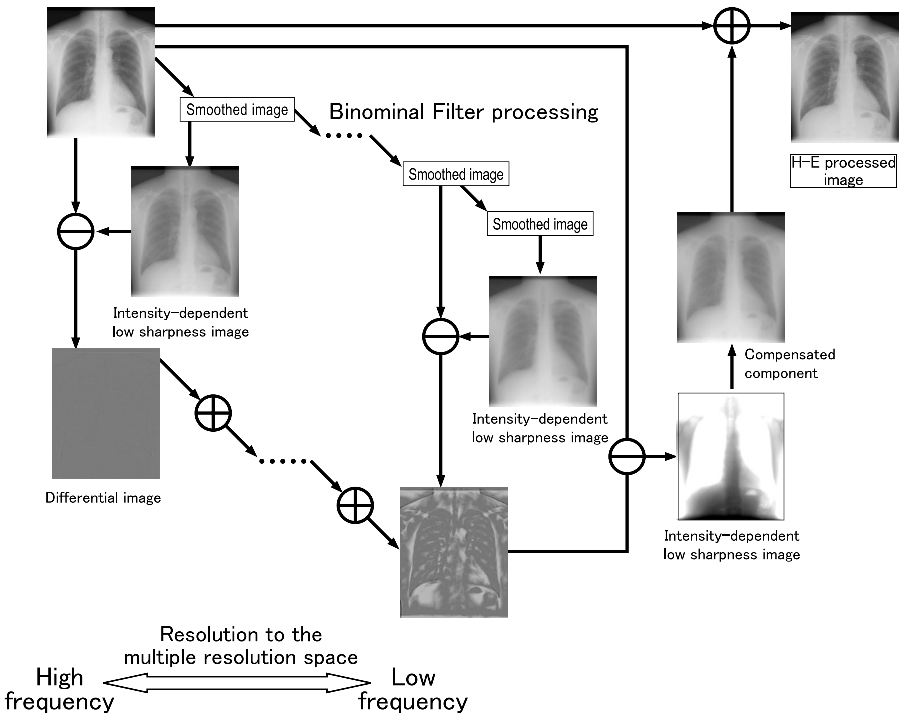


Figure 4-5-1. H-E processing algorithm

■ H-E PROCESSING

H-E parameters (intensified band)

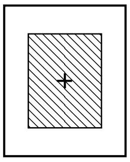
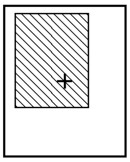
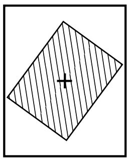
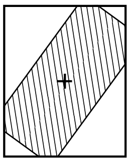
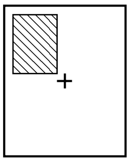
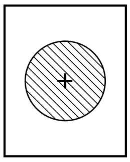
There are two kinds of H-E parameters from HE-standard 1 to HE-standard 2

H-E TYPE	Major applicable area	Explanation
HE-STANDARD1	Parts excluding Chest PA/AP and LAT chest	A type that emphasizes the edge of low intensity parts. Effective in cases that focus on the description of fine structures like bone beams.
HE-STANDARD2	Chest PA/AP, LAT chest	A type that emphasizes granularity in low intensity parts. Suppresses the deterioration of granularity under the diaphragm, etc.

Table 4-5-2. H-E type and applicable parts

Data 1 REGIUS Exposure Field Identification Type

REGIUS selects from three types of exposure field identification algorithm shown in the following table depending on the body part specified by the exam tag.

Type		Type1	Type3	Type5
Corresponding exposure field pattern		○	○	○
		○	○	○
		×	○	○
		×	○	○
		×	○	○
		×	×	○
Applicable body part		Chest PA/AP LAT Chest Abdomen simple Pelvis PA/AP etc.	Cervical vertebrae PA/AP LAT cervical vertebrae Thoracic vertebrae PA/AP LAT lumbar vertebrae etc.	Head Limb bones etc.

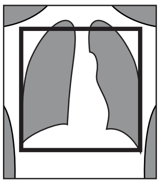
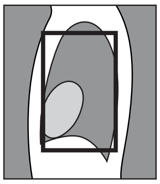
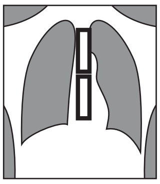
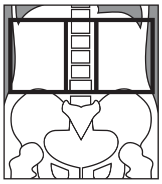
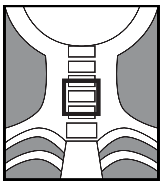
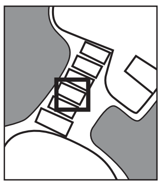
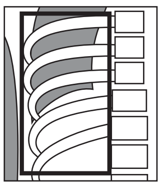
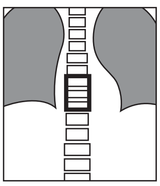
[Type 1]: Type 1 will be used to identify an exposure field that is quasi-parallel to the image end. It is useful for detecting an exposure field whose edge is comparatively vague due to dispersion rays.

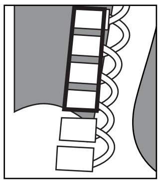
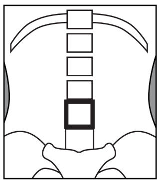
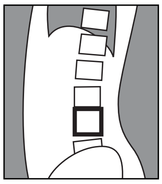
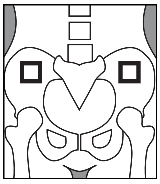
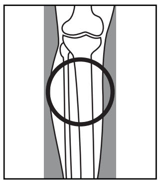
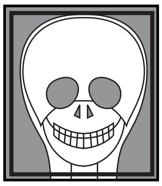
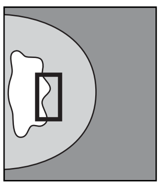
[Type 3]: Type 3 will be used to identify an exposure field that may be oblique at the image end. It is useful when the edge of the exposure field overlaps the exposure subject as is the case with the core of the human body.

[Type 5]: Type 5 will be used to identify an exposure field that may be oblique at the image end or to identify a quasi-circular field. It is useful for detecting an exposure field whose area is comparatively narrow.

REGIUS Exposure Field Identification Type

Data 2. REGIUS ROI Setup Algorithms

Type	Main processing name	ROI position		Reference signal value	Exposure field type
A	Chest PA/AP PED chest PA/AP	(ROI 1) Rectangle including the chest * If the transmission though one lung is exceptionally low, that lung is excluded. (ROI 2) None		(1) Minimum signal value for mediastinum area (2) Maximum signal value for lung area	1
B	LAT chest Chest oblique	(ROI 1) Rectangle including the chest (ROI 2) None		(1) Average signal value for lung area (2) None	1
C	Chest expiration observation	(ROI 1) Upper thoracic vertebrae (ROI 2) Lower thoracic vertebrae		(1) Average signal value for thoracic vertebrae (2) None	1
D	Abdomen simple	(ROI 1) The rectangle from the bottom of the lung area to the top of the ilium. (ROI 2) The vertebra within ROI 1		(1) Minimum signal value for soft abdomen area (2) The signal value near the flank stripe area	1
E	Cervical vertebrae PA/AP	(ROI 1) Fourth - sixth cervical vertebrae (ROI 2) None		(1) Signal value for the fourth - sixth cervical vertebrae (2) None	3
F	LAT cervical vertebrae Cervical vertebrae oblique	(ROI 1) Fourth - sixth cervical vertebrae (ROI 2) None		(1) Signal value for the fourth - sixth cervical vertebrae (2) None	3
G	Ribs	(ROI 1) Rectangle to flank excluding vertebra (ROI 2) None		(1) Signal value for low density area of ribs (2) Maximum signal value for lung area	1
H	Thoracic vertebrae PA/AP Thoracic lumbar vertebrae PA/AP	(ROI1) Vertebra in center region of exposure field (ROI2) None		(1) Signal value for the vertebra in center region of exposure field (2) None	3

Type	Main processing name	ROI position		Reference signal value	Exposure field type
I	LAT Thoracic vertebrae	(ROI1) Thoracic vertebra in lung area (ROI2) None		(1) None (2) Signal value for the vertebra in lung area	3
J	Lumbar vertebra PA/AP Abdomen KUB	(ROI1) Fourth lumbar vertebra (ROI2) None		(1) Signal value for the fourth lumbar vertebra (2) None	1
K	LAT lumbar vertebra Lumber vertebra oblique	(ROI1) Fourth lumbar vertebra (ROI2) None		(1) Signal value for the fourth lumbar vertebra (2) None	3
L	Pelvis PA/AP	(ROI1) Center of right ilium (ROI2) Center of left ilium		(1) Average signal value for center of ilium (2) None	1
M	Upper arm bone Elbow joint Knee joint PA/AP/LAT Lower leg bone * Also primarily processing of the extremities.	(ROI1) Circular region in center of exposure field. * If the subject part is not located in the center of the field adjust its position. (ROI2) None		(1) Signal value for the bone in the central area of the exposure field. (2) None	5
N	Head PA/AP Shoulder joint Hip joint PA/AP * Also primarily processing of parts including large bones.	(ROI1) Whole of exposure area (ROI2) None		(1) Minimum signal value in the exposed area of human body (2) None	5
O	Mammography	(ROI1) Rectangle covering the peripheral area of mammary gland (ROI2) None		(1) Signal value in peripheral area of mammary gland (2) None	—

Chapter5

X-Rays and Images

5.1 Relationship between Dose and Image

5.1.1 Differences between Screen/Film Systems and REGIUS

With screen/film systems, changing the X-ray dose may cause image density to suffer from under or over exposure. Furthermore, if the screen sensitivity is changed so the appropriate density can be obtained from the modified dose, both the sharpness and granularity of the image are changed.

On the other hand, the REGIUS has a function for automatic gradation; therefore, the intensity of images will not be affected by a variation in the X-ray dose. Furthermore, because the same detector is used each time, changes of X-ray dose do not cause changes of image sharpness and changes of image granularity are limited to those caused by the difference in X-ray dose.

Table 5-1-1 summarizes the relationship between image and changes in X-ray dose.
On the following pages, a diagram is used to explain the mechanism by which changes of X-ray dose affect the image, using an example where X-ray dose is reduced.

Modality	Precondition	Reduced X-ray dose	Increased X-ray dose
REGIUS	Automatic gradation processing	Density: Suitable Granularity: Degraded Sharpness: No change	Density: Suitable Granularity: Improved Sharpness: No change
Screen/ film	Using a more sensitive screen	Density: Suitable Granularity: Somewhat degraded Sharpness: Degraded	
	Using the same screen	Density: Under exposed Granularity: Good (low gamma) Sharpness: Degraded (low gamma)	Density: Over exposed Granularity: Improved (low gamma) Sharpness:q Degraded (low gamma)
	Using a less sensitive screen		Density: Suitable Granularity: Somewhat improved Sharpness: Improved

Table 5-1-1 Effect on image when X-ray dose is varied from the suitable dose

Figure 5-1-1(1) shows image density for a screen/film system when the X-ray dose is reduced without changing the screen.
When the X-ray dose is reduced, the image density is under-exposed.
Reducing the dose increases quantization noise, but because it affects the film in a low gamma dosage area, granularity does not become noticeable.

Figure 5-1-1(2) shows image density when the screen is replaced with one of high sensitivity.
The image density is now appropriate, but compared to a low sensitivity screen, the high sensitivity screen has a thicker film so that while the increase in quantization noise is reduced, there is a deterioration of image sharpness.
Accordingly, there is a worsening of both granularity and sharpness.

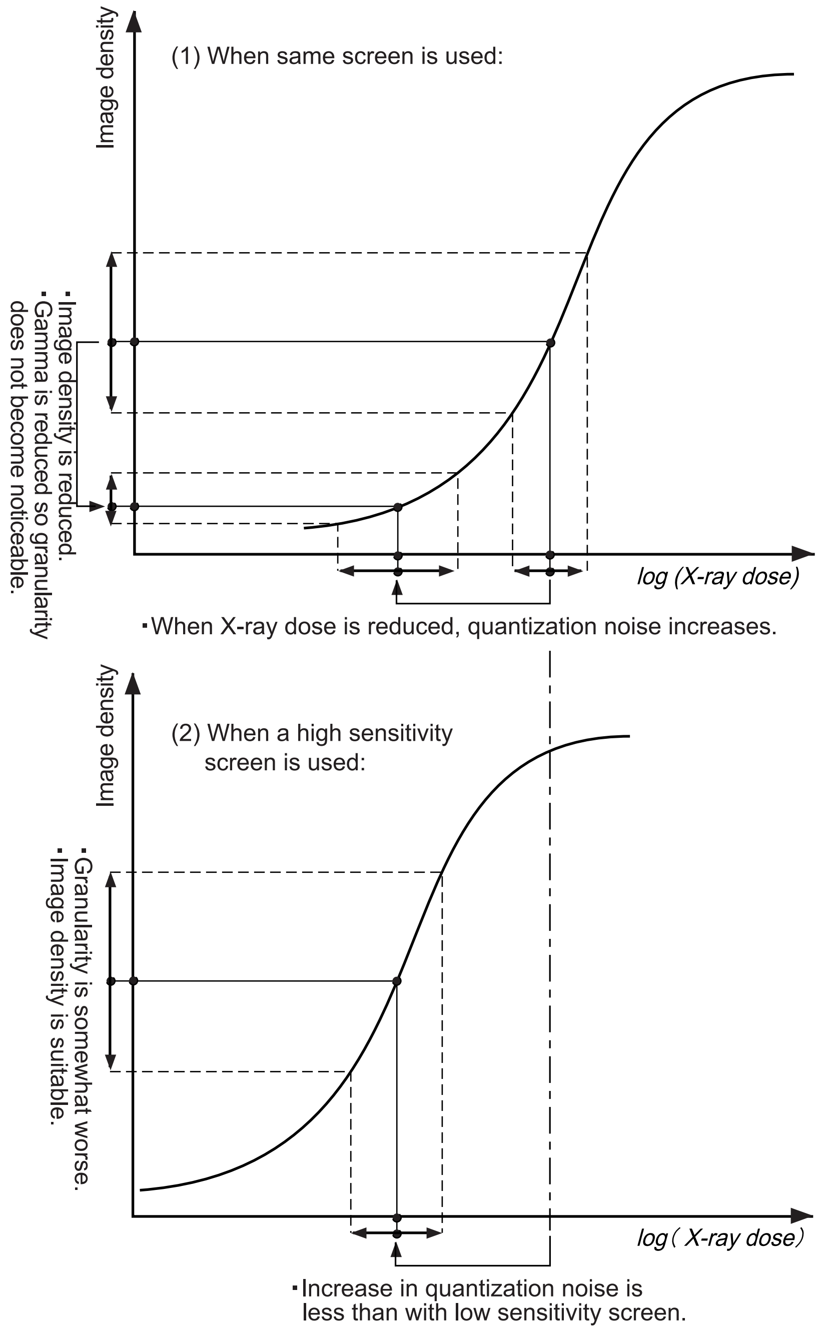


Figure 5-1-1 Changes to image for a screen/film system when Xray dose is reduced

Even when the X-ray dose is reduced as shown in Figure 5-1-2 (2) relative to the suitable X-ray dose shown in Figure 5-1-2(1), automatic gradation processing ensures that suitable image density is maintained.
Although the reduction of dose leads to an increase in quantization noise, owing to the use of the same detector there is no change to image sharpness.

However, even for REGIUS, if a fixed processing is used without normalization of image data, changes to the image resemble those for a screen/film system when the same screen is used with a changed X-ray dose.

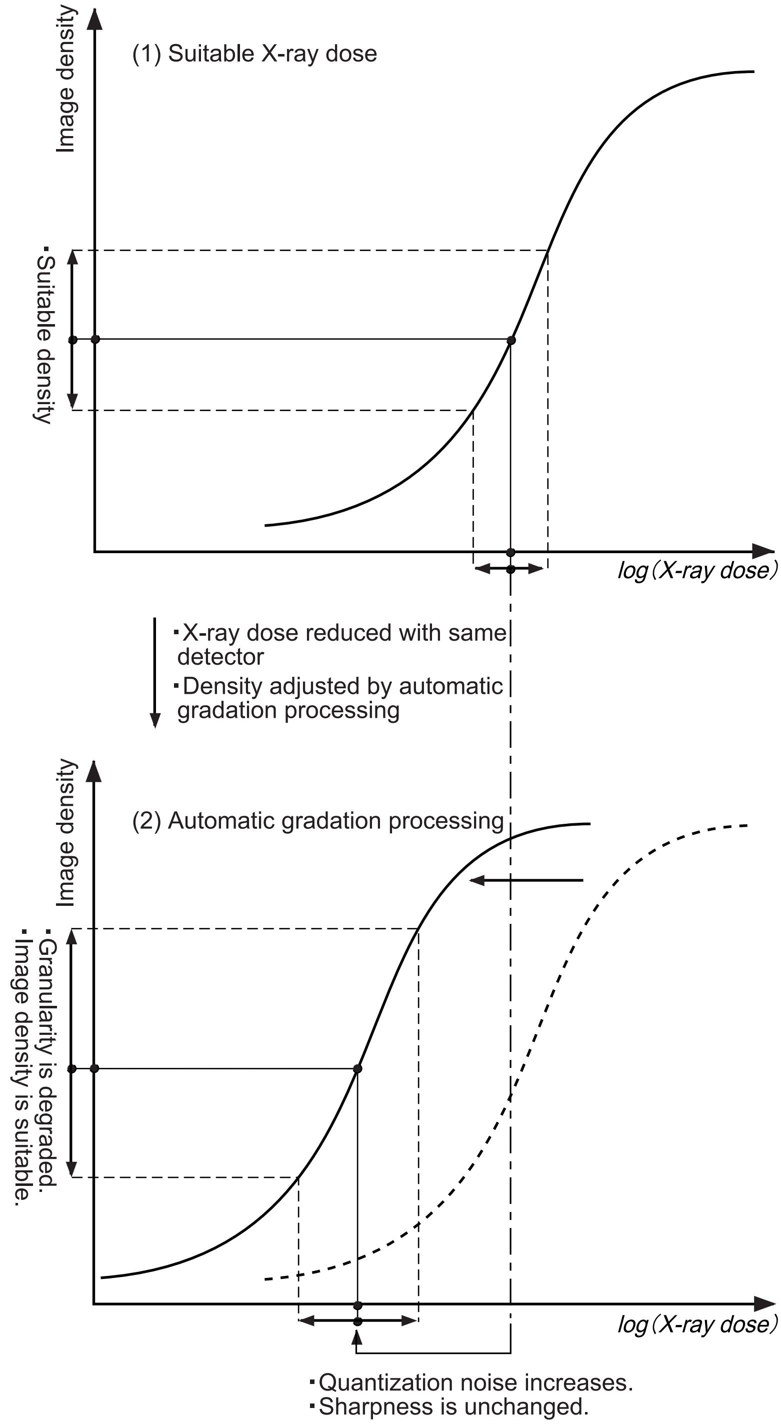


Figure 5-1-2 Changes to image when X-ray dose is reduced

REGIUS

From the above we can conclude that when images are subjected to REGIUS gradation processing, the effect of changing the X-ray dose is to cause a change of image granularity only, with density and sharpness remaining the same.
With REGIUS, when one wishes to change image density, this must be done not by changing the X-ray dose but by adjusting the gradation processing parameters.

As an example application of these features of REGIUS, in the following situations, depending on body part and diagnostic purpose, REGIUS offers the possibility of exposing patients to a lower X-ray dose than a screen/film system.

(a) In the case when the image granularity of a screen/film system with a sensitivity of the order of 250 is satisfactory and a slight worsening of granularity will not hamper diagnosis, but a screen of greater sensitivity than the one currently being used is not available, so to maintain a suitable density, there is no option other than to use the current X-ray dose.

(b) In the case when the image granularity of a screen/film system is satisfactory and a slight worsening of granularity will not hamper diagnosis, but if a screen of greater sensitivity were to be used, the image would not be sufficiently sharp so there is no option other than to use the current screen and current X-ray dose.

5.2 Relationship between Ray Quality and Image

5.2.1 Sensitivity Tube Voltage Characteristic

When the X-ray tube voltage is increased as shown in Figure 5-2-1, the sensitivity (intensity of emitted light) per unit (1mR) of X-ray dose also increases, and the image granularity improves proportionally. Also, if, for example, use is made of an Al 1.5mm Cu 0.1mm add on filter, the sensitivity per unit X-ray dose increases even for the same tube voltage, with this trend most evident at low tube voltages.

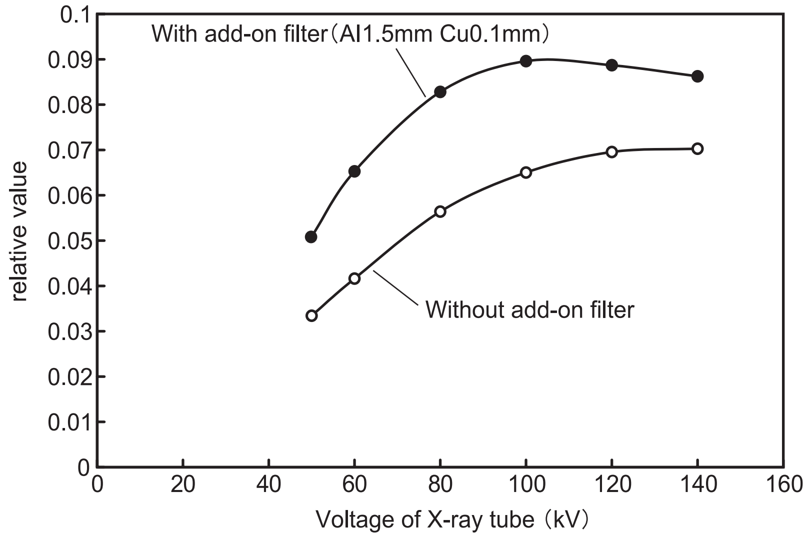


Figure 5-2-1 Sensitivity (intensity of emitted light) per unit (1mR) of X-ray dose tube voltage characteristic

Chapter6

Image Output

6.1 Hard Copy Output

Image data read by the CS-1 REGIUS 170 will be digitized, and they are output as hard copies in a variety of form (film output by imager)

The CS-1 is connected to the DRYPRO 771, DRYPRO 751/752, or DRYPRO 722 from Konica Minolta Inc. as an imager for hard copy output.

6.1.1 Image Output Parameters

Film size

[11"x14"], [14" x 14"], [14" x 17"] sizes may be selected.

Film orientation

Either portrait or landscape orientation can be selected.

Print format

Either "One image" or "Two images" can be selected.

"One image" outputs one image as it is viewed or outputs two images in up and down or right and left arrangements by changing the image processing. "Two images" outputs two images in either up and down or right and left arrangements.

Method of output

A choice can be made from the following methods.

Full scale output: output image is interpolated as full scale.

Whole output: whole image is interpolated so that the output size is maximum.

When "Full scale output" is selected, the image may be partially cut off due to the difference between the reading size and the output size. In that case, the reference position of the output can be selected from five options: Upper reference position, Center left reference position, Center reference position, Center right reference position, and Lower reference position. However, you can change the reference only when you set exam keys, and cannot change it when reading.

When "Whole output" is selected, output size may be reduced because reading size and output size are different. And, output size cannot be enlarged beyond full scale. Table 6-1-1 on the next page shows the reduction rates and trimming sizes for each reading size and output size.

DRYPRO752/751/722 (CT will be set on the DRYPRO)

Reading size	Output size		
	14" x 17"	14" x 14"	11"x14"
14" x 17"	95.5	77.8	77.3
14" x 14"	97.2	94.7	77.3
11"x14"	100.0	94.7	94.7
10" x 12"	100.0	100.0	100.0
8" x 10"	100.0	100.0	100.0
18 x 24cm (Mammography)	100.0	100.0	100.0

DRYPRO752/751/722 (REGIUS will be set on the DRYPRO)

Reading size	Output size		
	14" x 17"	14" x 14"	11"x14"
14" x 17"	99.5	81.8	78.2
14" x 14"	100.0	99.5	78.2
11"x14"	100.0	99.5	100.0
10" x 12"	100.0	100.0	100.0
8" x 10"	100.0	100.0	100.0
18 x 24cm (Mammography)	100.0	100.0	100.0

DRYPRO771 (CT will be set on the DRYPRO)

Reading size	Output size		
	14" x 17"	14" x 14"	11"x14"
14" x 17"	95.5	77.8	77.3
14" x 14"	97.2	94.7	77.3
11"x14"	100.0	94.7	94.7
10" x 12"	100.0	100.0	100.0
8" x 10"	100.0	100.0	100.0
18 x 24cm (Mammography)	100.0	100.0	100.0

DRYPRO771 (REGIUS will be set on the DRYPRO)

Reading size	Output size		
	14" x 17"	14" x 14"	11"x14"
14" x 17"	99.5	81.7	78.2
14" x 14"	100.0	99.5	78.2
11"x14"	100.0	99.5	99.9
10" x 12"	100.0	100.0	100.0
8" x 10"	100.0	100.0	100.0
18 x 24cm (Mammography)	100.0	100.0	100.0

Table 6-1-1. Reduction rates for the hard copy

(when "Whole output" is chosen)

6.2 Online Output

As an on-line output, the CS-1 implements the CR image storage service class (C-STORE) of DICOM (Digital Imaging and Communication in Medicine: A medical image and communication standard developed by the US Radiation Laboratory and North American Electronic Industries). This allows transmission of image data to servers within the facility such as storage and display devices etc., conforming to the DICOM standards.

6.2.1 Online Output Functions

CS-1 supports the following DICOM conformant functions.

Luminance Measurement Interpretation

Supports MONOCHROME 1 and MONOCHROME 2.
MONOCHROME 1 is an image data format that requires the minimum value (0) to be displayed by the server as white. MONOCHROME 2 is an image data format that requires the minimum value (0) to be displayed by the server as black.

JPEG Reversible Compression

This reversibly compresses image data using differential pulse code modulation (DPCM) so as to allow stable transmission of data with reduced network load.

Image processing

Following three image data can be output by the CS-1.

- No processing: raw data and image processing parameters will be output (raw data is the image data without any processing)
- Processed image data: P value output connecting to other equipment. Processed image data will be output in a linearly visible manner. The P value (presentation value) is the gradation defined in Part 14 of DICOM 3.0. It is a linear gradation based on the human vision model and is defined as equalizing the variation of the P value with the brightness change perceived by humans. If the monitors or imagers are calibrated by the GSDF (grayscale standard display function) curve, similar gradation can be obtained when the P value image is output irrespective of the dynamic range of the output device.
- Processed image data: D value output connecting to other equipment. Processed image data will be output as intensity values. The D value is the gradation where the pixel value corresponds to intensity linearly. The D value from 0 to 4095 (in the case of 12 bits) linearly correspond from Dmin to Dmax. This gradation has been used for the output to the imager in the past. However, the appearance of the gradation is too white and dull when displayed on a monitor without any processing. Some corrections have been made in order to provide an appropriate image when displayed on the REGIUS console monitor.

Japanese Text

CS-1 allows Japanese text (kanji, hiragana, katakana, katakana (Single-byte)) such as patient name, comments etc. entered into REGIUS to be transmitted to a server.

Overlay

By allowing information to be stored in a separate plane not used by the image data, the CS-1 allows overlay information to be added to images without loss of image data. However, this feature cannot be used with JPEG reversible compression.

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