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Standard Guide for ~~Computed Radiology (Photostimulable Luminescence (PSL) Method)~~Computed Radiography[1]

This standard is issued under the fixed designation E 2007; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

~~1.1This guide covers practices and image quality measuring systems for the detection, display, and recording of CR data files. These data files, used in materials examination, are generated by penetrating radiation passing through the subject material and producing an image via a storage phosphor imaging plate. Although the described radiation sources are specifically X-ray and gamma-ray, the general concepts can be used for other radiation sources such as neutrons. The image detection and display techniques are nonfilm, but the use of a hard copy as a means for permanent recording of the image is not precluded.~~

~~1.2This guide is for tutorial purposes only. It outlines the general principles of computed radiology (CR) imaging in which luminescence is emitted by a storage phosphor imaging plate, by means of photo stimulation after the detector has been penetrated by x-rays or gamma radiation.~~

~~1.3The values stated in SI units are to be regarded as the standard. The inch-pound units given in parentheses are for information only.~~

1.1 This guide provides general tutorial information regarding the fundamental and physical principles of computed radiography (CR), definitions and terminology required to understand the basic CR process. An introduction to some of the limitations that are typically encountered during the establishment of techniques and basic image processing methods are also provided. This guide does not provide specific techniques or acceptance criteria for specific end-user inspection applications. Information presented within this guide may be useful in conjunction with those standards of section 1.2.

1.2 CR techniques for general inspection applications may be found in Practice E 2033. Technical qualification attributes for CR systems may be found in Practice E 2445. Criteria for classification of CR system technical performance levels may be found in Practice E 2446. Reference Images Standard E 2422 contains digital reference acceptance illustrations.

1.3 The values stated in inch-pound units are to be regarded as standard. The values given in parentheses are mathematical conversions to SI units that are provided for information only and are not considered standard.

1.4 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.* ~~For specific safety precautionary statements, see Section 7.~~

2. Referenced Documents

2.1 *ASTM Standards:* [2]

E~~142 Method for Controlling Quality of Radiographic Testing~~ 94 Guide for Radiographic Examination

E 746 Practice for Determining Relative Image Quality Response of Industrial Radiographic Imaging Systems

E 747 Practice for Design, Manufacture and Material Grouping Classification of Wire Image Quality Indicators (IQI) Used for Radiology

E 1025 Practice for Design, Manufacture, and Material Grouping Classification of Hole-Type Image Quality Indicators (IQI) Used for Radiology

E~~1817Practice for Controlling Quality of Radiological Examination by Using Representative Quality Indicators (RQIs)~~ 1316 Terminology for Nondestructive Examinations

E 1453 Guide for Storage of Media that Contains Analog or Digital Radioscopic Data

E 2002 Practice for Determining Total Image Unsharpness in Radiology

E 2033 Practice for Computed Radiology (Photostimulable Luminescence Method)

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[1] This guide is under the jurisdiction of ASTM Committee E07 on Nondestructive Testing and is the direct responsibility of Subcommittee E07.01 on Radiology (X and Gamma) Method.

Current edition approved ~~Dec.~~July 1, ~~2006.~~2008. Published ~~January 2007.~~August 2008. Originally approved in 1999. Last previous edition approved in ~~2000~~2006 as E 2007 - 00(2006).

[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

E 2339 Practice for Digital Imaging and Communication in Nondestructive Evaluation (DICONDE)
E 2422 Digital Reference Images for Inspection of Aluminum Castings
E 2445 Practice for Qualification and Long-Term Stability of Computed Radiology Systems
E 2446 Practice for Classification of Computed Radiology Systems
2.2 ~~*Federal Standard:*~~
~~Fed. Std. No. 21-CFR 1020.40Safety Requirements for Cabinet X-Ray Machines~~ SMPTE Standard:
RP133 Specifications for Medical Diagnostic Imaging Test Pattern for Television Monitors and Hard-Copy Recording Cameras[3]

3. ~~Summary of Guide~~

~~3.1This guide outlines the practices for the use of CR methods and techniques for materials examination. It is intended to provide a basic understanding of the method and the techniques involved. The selection of a storage phosphor imaging plate, radiation source, and radiological techniques, which are necessary in achieving user CR performance requirements, is described.~~ Terminology

3.1 Unless otherwise provided within this standard guide, terminology is in accordance with Terminology E 1316.

3.2 *Definitions:*

3.2.1 *aliasing*—artifacts that appear in an image when the spatial frequency of the input is higher than the output is capable of reproducing. This will often appear as jagged or stepped sections in a line or as moiré patterns.

3.2.2 *basic spatial resolution* (SR_b)— the read-out value of unsharpness divided by 2 as effective pixel size of the CR system (Practices E 2445 and E 2446).

3.2.3 *binary/digital pixel data*—a matrix of binary (0's, 1's) values resultant from conversion of PSL from each latent pixel (on the IP) to proportional (within the bit depth scanned) electrical values. Binary digital data value is proportional to the radiation dose received by each pixel.

3.2.4 *bit depth*—the number "2" increased by the exponential power of the analogue-to-digital (A/D) converter resolution. Example 1): in a 2 bit image, there are four (2^2) possible combinations for a pixel: 00, 01, 10 and 11. If "00" represents black and "11" represents white, then "01" equals dark gray and "10" equals light gray. The bit depth is two, but the number of gray levels that can be represented is 2^2 or 4. Example 2): a 12 bit A/D converter would have 4096 (2^{12}) gray levels that can be represented.

3.2.5 *blooming or flare*—an undesirable condition exhibited by some image conversion devices brought about by exceeding the allowable input brightness for the device, causing the image to go into saturation, producing an image of degraded spatial resolution and gray scale rendition.

3.2.6 *computed radiographic system*—all hardware and software components necessary to produce a computed radiograph. Essential components of a CR system consisting of: an imaging plate, an imaging plate readout scanner, electronic image display, image storage and retrieval system and interactive support software.

3.2.7 *computed radiographic system class*—a group of computed radiographic systems characterized with a standard image quality rating. Practice E 2446, Table 1, provides such a classification system.

3.2.8 *computed radiography*—a radiological nondestructive testing method that uses storage phosphor imaging plates (IP's), a PSL stimulating light source, PSL capturing optics, optical-to-electrical conversion devices, analogue-to-digital data conversion electronics, a computer and software capable of processing raw digital image data and a means for electronically displaying or printing resultant image data.

3.2.9 *contrast and brightness*—an application of digital image processing used to "re-map" displayed gray scale levels of an original gray scale data matrix using different reference lookup tables.

3.2.9.1 *Discussion*—This mode of image processing is also known as "windowing" (contrast adjustment) and "leveling" (brightness adjustment) or simply "win-level" image processing.

3.2.10 *contrast-to-noise ratio (CNR)*—terminology used to describe image quality associated with a quotient of contrast and noise level within the image.

3.2.11 *detector signal-to-noise ratio* (SNR_D)—quotient of mean pixel value and standard deviation of pixel value noise (and intensity distribution) for a defined detector area-of-interest and ISO exposure dose (see Practice E 2446).

3.2.11.1 *Discussion*—Notwithstanding extraneous sources of digital image noise, SNR_D will normally increase as ISO exposure dose is increased over the useful exposure range of the detector. SNR_D is intended for evaluation of detector performance without influence of absorbing materials.

3.2.12 *digital driving level (DDL)*—terminology used to describe displayed pixel brightness of a digital image on a monitor resultant from digital mapping of various gray scale levels within specific look-up-table/s.

3.2.12.1 *Discussion*—DDL is also known as monitor pixel intensity value; thus, may not be the PV of the original digital image.

3.2.13 *digital dynamic range*—maximum material thickness latitude that renders acceptable levels of specified image quality performance within a specified pixel intensity value range.

3.2.13.1 *Discussion*—Digital dynamic range should not be confused with computer file bit depth.

3.2.14 *digital image contrast*—pixel intensity value difference between any two areas of interest within a computed radiograph.

[3] Available from Society of Motion Picture and Television Engineers (SMPTE), 3 Barker Ave, 5th Floor, White Plains, NY 10601.

3.2.14.1 *Discussion*—digital contrast = PV2 – PV1 where PV2 is the pixel value of area of interest "2" and PV1 is the pixel value of area of interest "1" on a computed radiograph.

3.2.15 *digital image noise*—imaging information within a computed radiograph that is not directly correlated with the degree of radiation attenuation by the object or feature being examined, or insufficient radiation quanta absorbed within the detector IP, or both.

3.2.15.1 *Discussion*—Digital image noise results from random spatial distribution of photons absorbed within the IP and interferes with the visibility of small or faint detail due to statistical variations of pixel intensity value.

3.2.16 *digital image processing*—the use of algorithms to change original digital image data for the purpose of enhancement of some aspect of the image.

3.2.16.1 *Discussion*—Examples include: contrast, brightness, pixel density change (digital enlargement), digital filters, gamma correction and pseudo colors. Some digital processing operations such as sharpening filters, once saved, permanently change the original binary data matrix (Fig. 1, Step 5).

3.2.17 *equivalent penetrameter sensitivity (EPS)*— that thickness of penetrameter, expressed as a percentage of the section thickness radiographed, in which a 2T hole would be visible under the same radiographic conditions. EPS is calculated by: EPS% = 100/ X ($\sqrt{Th/2}$), where: h = hole diameter, T = step thickness and X= thickness of test object (see E 1316, E 1025, E 747, and Practice E 746).

3.2.18 *gray scale*—a term used to describe an image containing shades of gray rather than color. Gray scale is the range of shades of gray assigned to pixel values that determines pixel display brightness.

3.2.18.1 *Discussion*—The number of shades is usually positive integer values taken from the bit depth. For example: an 8-bit gray scale image has up to 256 total levels of gray from 0 to 255, with 0 being white and 255 being black with 254 gray levels in between.

3.2.19 *image morphing*—a potentially degraded CR image resultant from over processing (that is, over driving) an original CR image.

3.2.19.1 *Discussion*—"Morphing" can occur following several increments of image processing/file save cycles where each preceding image was "overwritten" resulting in an image that is noticeably altered from the original.

3.2.20 *look up table (LUT)*—one or more fields of binary digital values arbitrarily assigned to a range of reference gray scale levels (viewed on an electronic display as shades of "gray").

3.2.20.1 *Discussion*—A LUT is used (applied) to convert binary digital pixel data to proportional shades of "gray" that define the CR image. LUT's are key reference files that allow binary digital pixel data to be viewed with many combinations of pixel gray scales over the entire range of a digital image (see Fig. 2A).

3.2.21 *measured unsharpness*—a term used to describe an attribute of image quality associated with blurring within a radiographic image. Discussion:

3.2.21.1 *Discussion*—Measured unsharpness is described with a numerical value corresponding with a measure of resolution

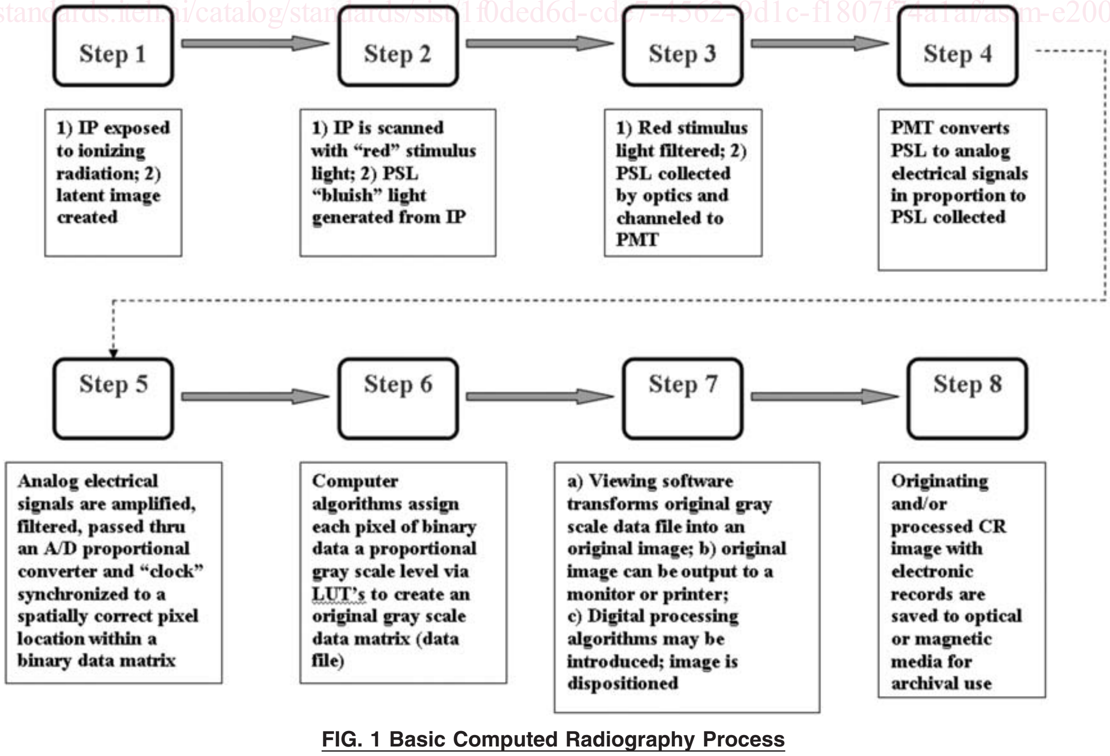
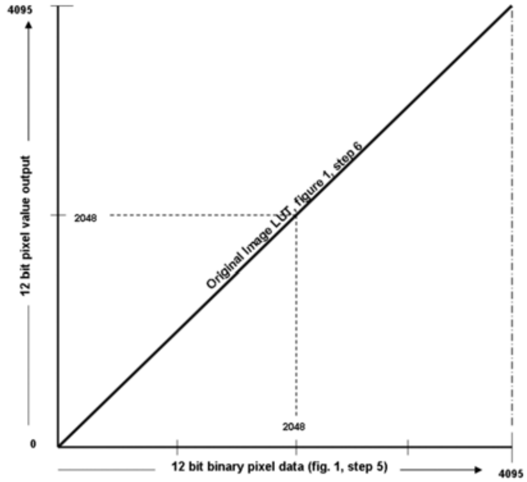


FIG. 1 Basic Computed Radiography Process

12 Bit Binary Pixel Data (fig. 1, step 5)	Original LUT (fig. 1, step 6)
0	0
1	1
10	2
11	3
100	4
101	5
↓	↓
111111111111	4095
4096 Increments of binary data	4096 Increments of gray scales

(A) Sample 12 bit Look-up Table



(B) Graph version of applied LUT

FIG. 2 (A) Sample 12 bit Look-up Table (B) Graph Version of Applied LUT

taken from a line pair gauge (line pairs per mm) or from a duplex wire gauge (width of wires just merged). Measured unsharpness is the total of geometrical and inherent unsharpness within an image.

3.2.22 *normalized signal-to-noise ratio (SNR_N)*—detector signal-to-noise ratio (SNR_D pixel statistics) mathematically combined with a measure of detector basic spatial resolution (SR_b) on the same radiographic image.

3.2.22.1 *Discussion*—SNR_N is calculated by: $I_{meas}/\ \sigma_{PSl} \times$ (BSR/88.6) and is used to classify digital detector system performance (see Practice E 2446). SNR_N is highly influenced by quantity of exposure dose.

3.2.23 *original digital image*—a digital gray scale image resultant from application of original binary digital pixel data to a look-up table prior to any image processing.

3.2.23.1 *Discussion*—this gray scale image is usually considered the beginning of the "computed radiograph", since without this basic conversion (to gray scales) there would be no discernable radiographic image (see Fig. 2B).

3.2.24 *photostimulable luminescence (PSL)*—photo stimulated luminescence (PSL) is a physical phenomenon in which a phosphor that has ceased emitting light because of removal of the stimulus once again emits light when excited by light with a longer wavelength than the emission wavelength.

3.2.25 *pixel brightness*—the luminous (monitor) display intensity of pixel/s that can be controlled by means of electronic monitor brightness level settings or changes of digital driving level (see 3.2.12).

3.2.26 *pixel density*—the number of pixels within a digital image of fixed dimensions (that is, length and width).

3.2.26.1 *Discussion*—For digital raster images, the convention is to describe pixel density in terms of the number of pixel-columns (width) and number of pixel rows (height). An alternate convention is to describe the total number of pixels in the image area (typically given as the number of mega pixels), which can be calculated by multiplying pixel-columns by pixel-rows. Another convention includes describing pixel density per area-unit or per length-unit such as pixels per in./mm. Resolution (see 7.1.6) of a digital image is related to pixel density.

3.2.27 *pixel value (PV, also known as gray value)*— a positive integer numerical value within the gray scale values of a picture data element (pixel) directly proportional with binary pixel data values of a digital image.

3.2.27.1 *Discussion*—PV is directly related to binary pixel data via a look-up-table (Fig. 2 illustrates). The number of available PV's is associated with gray scale bit depth of digital image.

3.2.28 *relative image quality response (RIQR)*— a means for determining the image quality performance response of a given radiological imaging system in relative comparison to the image quality response of another radiological imaging system.

3.2.28.1 *Discussion*—RIQR methods are not intended as a direct measure of image quality for a specific radiographic technique application. Practice E 746 provides a standard RIQR method.

3.2.29 *storage phosphor imaging plate (IP)*—a photostimulable luminescent material that is capable of storing a latent radiographic image of a material being examined and, upon stimulation by light of appropriate wavelength, will generate luminescence (PSL) proportional to radiation absorbed.

3.2.29.1 *Discussion*—When performing computed radiography, an IP is used instead of a film. When establishing techniques related to source focal geometries, the IP is referred to as a detector (that is, source-to detector-distance or SDD).

4. Significance and Use

~~4.1This guide establishes an introduction to the theory and use of CR. The X-, gamma-ray detector discussed in this guide is a storage phosphor imaging plate, hereafter referred to as SPIP. The SPIP, which is the key component in the CR process, differentiates CR from other radiologic methods. This guide is a tutorial standard, and therefore it does not present specified image~~

~~quality levels as would be used to address the acceptance or rejection criteria established between two contracting parties, for example, NDT facility or consumer of NDT services, or both. It is not a detailed how-to procedure to be used by the NDT facility or consumer of NDT service, or both.~~

~~4.2Table 1 lists the general performance, complexity, and relative cost of CR systems.~~

4.1 This guide is intended as a source of tutorial and reference information that can be used during establishment of computed radiography techniques and procedures by qualified CR personnel for specific applications. All materials presented within this guide may not be suited for all levels of computed radiographic personnel.

4.2 This guide is intended to build upon an established basic knowledge of radiographic fundamentals (that is, film systems) as may be found in Guide E 94. Similarly, materials presented within this guide are not intended as "all-inclusive" but are intended to address basic CR topics and issues that complement a general knowledge of computed radiography as described in 1.2 and 4.3.

4.3 Materials presented within this guide may be useful in the development of end-user training programs designed by qualified CR personnel or activities that perform similar functions. Computed radiography is considered a rapidly advancing inspection technology that will require the user maintain knowledge of the latest CR apparatus and technique innovations. The REFERENCES section of this guide contains technical reference materials that may be useful in further advancement of knowledge associated with computed radiography.

5. ~~Background~~

~~5.1Inspired by the success of computed tomography (CT), new methods of radiologic imaging have been developed that utilize recent advances in electronics and computer technologies to realize better image quality, and to evolve new imaging modalities. These are generally in a category in which the X-ray sensor is mainly either the conventional image intensifier and television-camera combination or the linear array sensor as used in CT. The basic quality of the digital image is not limited by digital processing but in large measure by the performance of the sensor itself in regard to spacial resolution and signal to noise ratio.~~

~~5.2The earliest written reference to fluorescence, the phenomenon which causes materials to emit light in response to external stimuli, dates back to 1500 B.C. in China. This phenomenon did not attract scientific interest until 1603, when the discovery of the Bolognese stone in Italy led to investigation by a large number of researchers. One of these was Becquerel, who, in his 1869 book *La Lumiere*, revealed that he had discovered the phenomenon of stimulated luminescence in the course of his work with phosphors.~~

~~5.2.1Photo stimulated luminescence (PSL) is a phenomenon in which a phosphor that has ceased emitting light because of the removal of the stimulus once again emits light when excited by light with a longer wavelength. The phenomenon is quite common since photostimulable phosphors cover a broad range of materials—compounds of elements from Groups IIB and VI (for example, ZnS), compounds of elements from Groups 1A and VIIA, VIIB and V VIB (for example, alkali halides), diamond, Groups 2A and VIIA, VIIB and V VIB (for example, barium fluorohalides—Ba FX-EU^{2+} X=Br, I, etc.), oxides (for example, Zn2Si04:Mn and LaOBr:Ce, Tb), and even certain organic compounds. The materials therefore lend themselves to data storage because the stimulus or primary excitation could be used to write data to the material, the light or secondary excitation to read the data back. Storage phosphor imaging plate (IP) is a name given to a two-dimensional flexible sensor that can store a latent image obtained from X rays, electron beams or other types of radiation, using photostimulable phosphors (P.P.), and then sequentially reproduces them as a digital file by releasing the PSL with a laser beam, piping the PSL to a photomultiplier tube (PMT) and then digitizing the resulting electrical signal.~~

~~5.3With the introduction of photostimulable luminescence imaging systems in the early 1980's, CR was born by the combination of this highly advanced photographic technology with recent advances in computer technologies.~~

~~5.4CR can utilize various software algorithms for image enhancement and optical disks for digital file storage. This advanced imaging system greatly expands the versatility of radiology. Potential industrial applications include production examination of aircraft components, welds in rocket-motor housings, castings, transistors, microcircuits, circuit-boards, valve positions, erosion and corrosion of pipes, integrity of pipe welds, solenoid valves, fuses, relays, tires, reinforced plastics and automotive parts.~~

~~5.5*Limitation*:~~

~~5.5.1*Handling Characteristics*—Potentially, a CR imaging plate may be erased and reused thousands of times. The primary limiting factor, as is the case with lead intensifying screens, is physical handling. Frequency of handling, bending and cleaning determines the plate's useful lifespan.~~ Computed Radiography Fundamentals

5.1 This section introduces and describes primary core components and processes of a basic computed radiography process. The user of this standard guide is advised that computed radiography is a rapidly evolving technology where innovations involving core steps and processes are continually under refinement. Tutorial information presented in this section is intended to illustrate the fundamental computed radiography process and not necessarily any specific commercial CR system.

5.2 *Acquiring the CR Image*: Computed radiography (CR) is one of several different modes of digital radiography that employs re-usable photostimulable luminescence (PSL) storage phosphor imaging plates (commonly called IP's) for acquisition of radiographic images. Figure 1 illustrates an example of the fundamental steps of a basic CR process arrangement.

5.2.1 In this illustration, a conventional (that is, Guide E 94) radiographic exposure geometry/arrangement is used to expose a part positioned between the radiation source and IP. Step 1 involves exposure of the IP (Fig. 3 illustrates typical cross section details of an IP) and creation of a residual latent image with delayed luminescence properties (section 6 details physics).

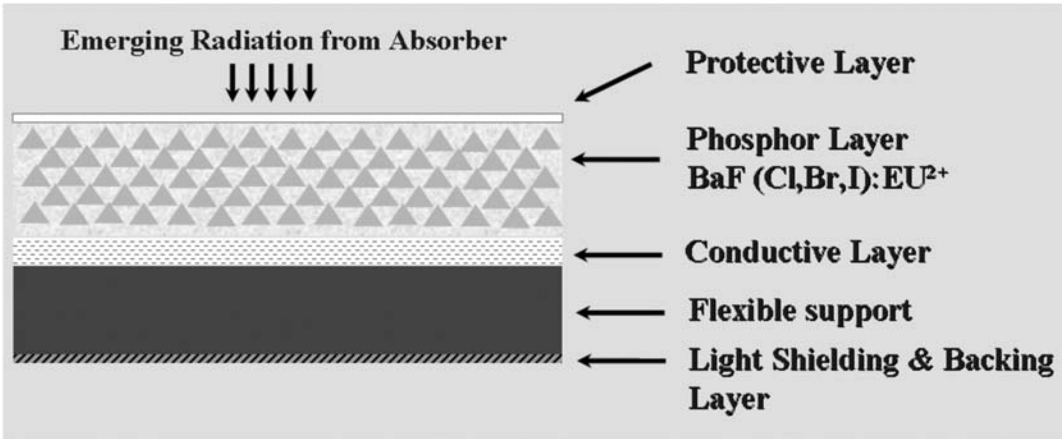


FIG. 3 Cross Section of a Typical Storage Phosphor Imaging Plate

5.2.2 Step 2 involves index scanning the exposed IP with a stimulus source of red light from a laser beam (Fig. 4 illustrates Steps 2 through 8).

5.2.3 During the scan, the IP is stimulated to release deposited energy of the latent image in the form of bluish photostimulated visible light. Step 3: the bluish photostimulated light (PSL) is then collected by an optical system containing a chromatic filter (that prevents the red stimulus light from being collected) and channeled to a photo-multiplier tube (PMT). Step 4: PSL light is converted by the PMT to analogue electrical signals in proportion to quantity of PSL collected. Step 5: analog electrical signals are amplified, filtered, passed through an analog–to–digital (A/D) converter and "clock" synchronized to a spatially correct pixel location within a binary data matrix (Fig. 5 illustrates assignment of binary data to a pixel matrix).

5.2.4 The actual size of the binary pixel element (length and width) is determined by the scanning speed of the transport mechanism in one direction and the clock speed of the sampling along each scan line (how fast the laser spot moves divided by the sampling rate). Although resolution is limited by pixel size, the size of individual phosphor crystals, the phosphor layer thickness of the image plate, laser spot size and optics also contribute to the overall quality (resolution) of the image. Each of these components thus becomes a very essential contributor to the overall binary storage matrix that represents the latent digital image. These individual elements represent the smallest unit of storage of a binary digital image that can be discretely controlled by the CR data acquisition and display system components and are commonly called "pixels". The term "pixel" is thus derived from two word components of the digital matrix, that is, picture (or pix) and elements (els) or "pixels". Picture elements or pixels represent the heart and soul of a digital image and thus become the basis for all technical imaging attributes that comprise quality and

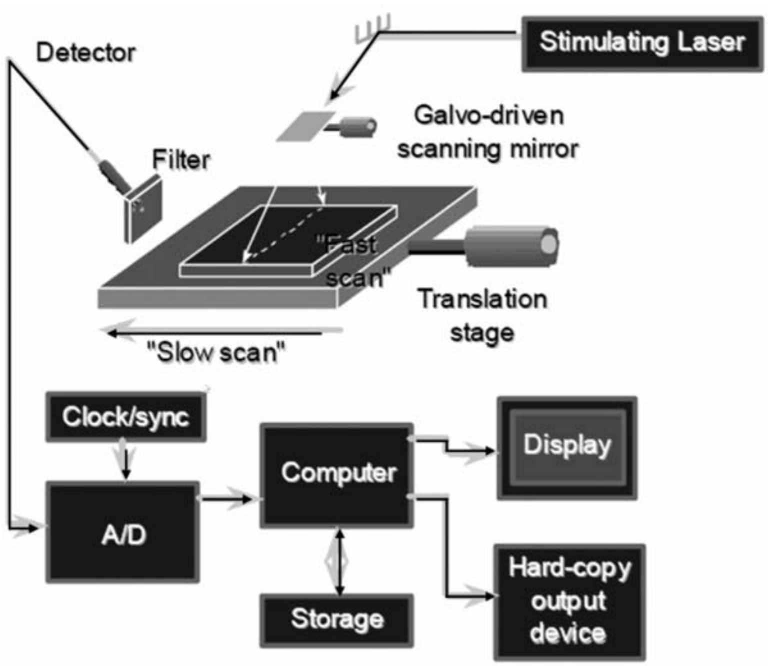


FIG. 4 Fundamental CR Image Acquisition and Display Process

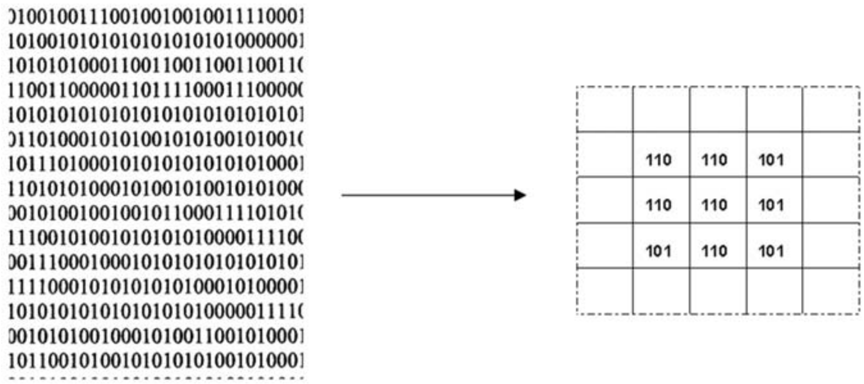


FIG. 5 Assignment of Binary Data to a Pixel Matrix (3 bit depth illustrated)

composition of the resultant image. An organized matrix of picture elements (pixels) containing binary data is called a binary pixel data matrix since proportional gray levels have not yet been assigned. (Ref (**2**) contains basic tutorial information on binary numbering system and its usefulness for digital applications).

5.2.5 *Step 6*: computer algorithms (a string of mathematical instructions) are applied that match binary pixel data with arbitrary files (called look-up-tables) to assign individual pixel gray scale levels. An example is to assign gray scale levels in proportion to the magnitude of the binary numbers (that is, a higher binary number associated with a greater amount of photo stimulated light for that pixel registration can be assigned a darker gray value) to create an original gray scale data matrix with a standard format (DICONDE, TIFF, BITMAP, etc) ready for software transformation. Figure 2A illustrates a simple linear look-up-table for an original "negative" gray scale data matrix and Fig. 2B illustrates a graphical version of the application as might be applied by an algorithm to produce an image with a "negative" gray tonal appearance (visually similar to a radiographic film negative). Most algorithms employed for original CR images assign gray scale values in linear proportion to the magnitude of each binary pixel (value). The range (number) of selectable gray values is defined within the image viewing software as "bit depth".

5.2.6 *Step 7*: a) viewing software is used to transform the original gray scale data matrix into an original image; b) the original image can be output to an electronic display monitor or printer; the resultant CR digital image can have a similar "negative" gray tonal appearance as its film counterpart (as illustrated with the LUT shown in Fig. 2A) in that as gray values become larger, displayed luminance becomes smaller. With the negative digital image display, inspected features can pretty much be characterized and dispositioned similar to a radiographic film negative. Both image modalities require evaluations within environments of subdued background lighting. Aside from these basic similarities, however, the CR digital image is an entirely different imaging modality that requires some basic knowledge of digital imaging fundamentals in order to understand and effectively apply the technology; c) once the original digital image is visualized, additional image processing techniques (see Section 8) may be performed to further enhance inspection feature details and complete the inspection evaluation process. This entire process is called computed radiography because of the extreme dependence on complex computational processes in order to render a meaningful radiographic image. Finally (Step 8), original and/or processed digital images and related electronic records may be saved to optical, magnetic or print media for future use. Some applications may benefit from a high quality digital print of the saved image. Typical CR system commercial hardware components are illustrated in Fig. 6. Computed radiographic technology is complex in

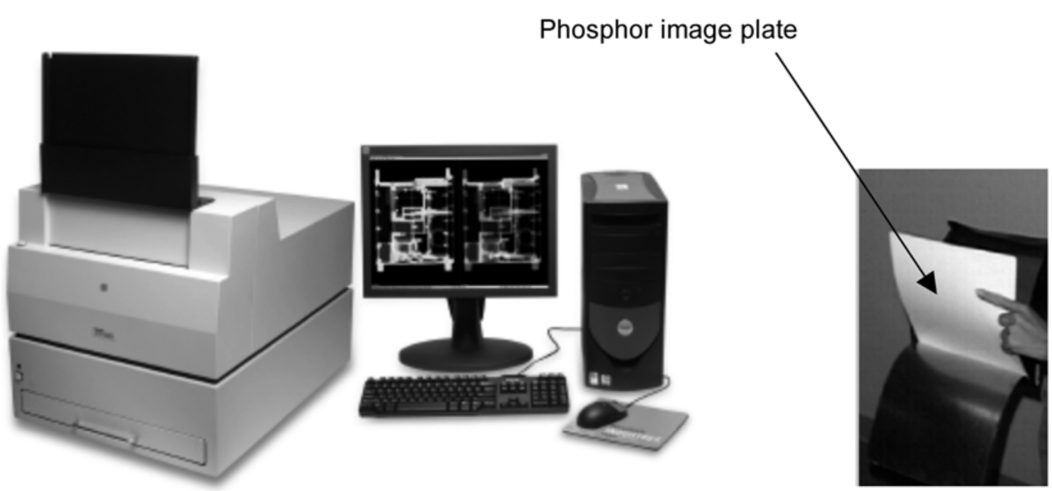


FIG. 6 Typical CR Scanner, Workstation and Image Plate

nature; therefore, subsequent sections of this standard are intended to provide some additional levels of detail associated with the basic computed radiography process. Additional levels of information may be found within the REFERENCES section at the end of this guide.

6. ~~Interpretation and Reference Standards~~ Brief History and Physics of Computed Radiography

6.1 ~~*Acceptance Standards*—As written by other organizations for film radiography may be employed for CR inspection provided appropriate adjustments are made to accommodate the differences represented by the CR data files.~~ Photo Stimulated Luminescence: Photo stimulated luminescence (PSL) is a physical phenomenon in which a phosphor that has ceased emitting light because of removal of the stimulus once again emits light when excited by light with a longer wavelength than the emission wavelength. In other words, phosphors capable of "PSL" exhibit a unique physical property of delayed release of visible light subsequent to radiation exposure; thus, the reason this type of phosphor is sometimes referred to as a "storage phosphor". Figure 7 illustrates the photo excitation process when this phosphor is exposed (following exposure of the phosphor to radiation) to a source of red light (He-Ne or semiconductor laser). The "bluish-purple" light emitted during this stimulation is referred to as "photostimulated luminescence" or "PSL" for short. During collection of PSL light for computed radiography, the red light source is separated from PSL using a chromatic filter (see Fig. 4). The "PSL" process is the very heart of CR technology and is thus important for understanding how computed radiography works.

6.2 ~~*ASTM Reference Standards*—Reference digital image standards, complementing existing ASTM reference film radiographic standards must be developed. Subcommittee E07.01 work aimed at developing such standards is underway.~~

~~7.Safety Precautions~~

~~7.1The safety procedures for the handling and use of ionizing radiation sources must be followed. Mandatory rules and regulations are published by governmental licensing agencies, and guidelines for control of radiation are available in publications such as the Fed. Std. No. 21-CFR 1020.40. Careful radiation surveys should be made in accordance with regulations and codes and should be conducted in the examination area as well as adjacent areas under all possible operating conditions.~~

~~8.Radiation Sources~~

~~8.1*General*:~~

~~8.1.1The sources of radiation for CR imaging systems described in this guide are X-ray machines and radioactive isotopes. The energy range available extends from a few kV to 32 MeV. Since examination systems in general require high dose rates, X-ray machines are the primary radiation source. The types of X-ray sources available are conventional X-ray generators that extend in energy up to 420 kV. Energy sources from 1 MeV and above are generally represented by linear accelerators.~~

~~8.1.2Usable isotope sources have energy levels from 84 keV (Thulium-170, Tm^{170}) up to 1.25 MeV (Cobalt-60, Co^{60}). With high specific activities, these sources should be considered for special application where their field mobility and operational simplicity can be of significant advantage.~~

~~8.1.3The factors to be considered in determining the desired radiation source are energy, focal geometry, wave form, half life, and radiation output.~~

~~8.2*Selection of Sources*:~~

~~8.2.1*Low-Energy Sources*—The radiation source selected for a specific examination system depends upon the material being examined, its mass, its thickness, and the required rate of examination. In the energy range up to 420 kV, the X-ray units have an adjustable energy range so that they are applicable to a wide range of materials. Specifically, 50-kV units operate down to a few kV; 160-kV equipment operates down to 20 kV; and 420-kV equipment operates down to about 85 kV.~~

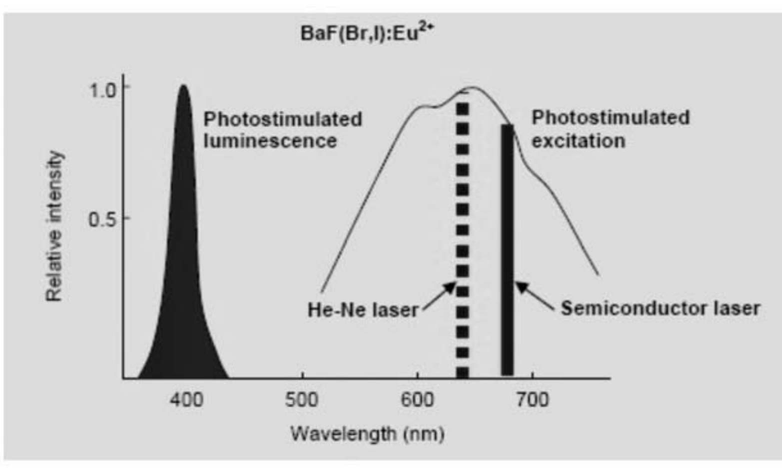


FIG. 7 Spectra of Photostimulated Luminescence and Excitation

~~8.2.2*High-Energy Sources*—The increased efficiency of X-ray production at higher accelerating potentials makes available a large radiation flux, and this makes possible the examination of greater thicknesses of material. High radiation energies in general produce lower image contrast, so that as a guide the minimum thickness of material examined should not be less than 2.5 half-value layers of material. The maximum thickness of material can extend up to 10 half-value layers.~~ Early History of Photo Stimulated Luminensce : The earliest written reference to fluorescence, the phenomenon that causes materials to emit light in response to external stimuli, dates back to 1500 B.C. in China. This phenomenon did not attract scientific interest until 1603, when the discovery of the Bolognese stone in Italy led to investigation by a large number of researchers. One of these was Becquerel, who, in his 1869 book *La Lumiere*, revealed that he had discovered the phenomenon of stimulated luminescence in the course of his work with phosphors. Photo stimulated luminescence (PSL) is a phenomenon which is quite common since photostimulable phosphors cover a broad range of materials—compounds of elements from Groups IIB and VI (for example, ZnS), compounds of elements from Groups 1A and VIIB (for example, alkali hydrides), diamond, oxides (for example, Zn2Si04:Mn and LaOBr;Ce,Tb), and even certain organic compounds. The materials, therefore, lend themselves to data storage because radiation could be used to write data to the material, the light or secondary excitation to read the data back. Storage phosphor imaging plate (IP) is a name given to a two dimensional sensor (see Fig. 3) that can store a latent image obtained from X-rays, electron beams or other types of radiation, using photostimulable phosphors.

6.3 *Recent History of Computed Radiography*: With the introduction of photostimulable luminescence imaging systems in the early 1980's in combination with continued advancements in computer technologies, CR was "born". In the early 1990's, further advancements in computer technologies in conjunction with refined phosphor imaging plate developments initiated limited applications, mostly driven by the medical industry. The medical industry became interested in CR for several reasons: 1) the desire for electronic transport of digital images for remote diagnostics and 2) the increased latitude of diagnostic capability with a single patient exposure. Throughout the 90's, technology advancements in CR were driven primarily by the medical industry for similar reasons. In the late 90's, as image quality attributes continued to improve, industrial radiographers became more interested in CR for its ability to detect small features within heavier materials with reliabilities approaching some classes of film systems. In 1999, continued industrial user interests led to the development and publication of ASTM's first computed radiography standard, E 2033-99 "Standard Practice for Computed Radiology". ASME adopted its first article for ASME Code compliant computed radiography in 2004. In 2005, further interests from industrial users led to the development and publication of Practice E 2445 and Practice E 2446. ASTM published its first ever set of all-digital reference images (E 2422) for the inspection of aluminum castings in 2005.

6.4 *PSL Crystal Structure*: Fig. 8 illustrates the basic physical structure of a typical Barium Fluorohalide phosphor crystal. Figure 9 illustrates a photo-micrograph of these type crystal grains as seen through a scanning electron microscope at approximately 10 microns. These crystal structures are the basis of the phosphor layer shown in Fig. 3 and constitute the heart of the physical "PSL" process described in the following text.

6.5 *Latent Image Formation*: A widely accepted mechanism for PSL in europium-activated halides was proposed by Takahashi et al (**10**). In the phosphor-making process, halogen ion vacancies, or "F^+" centers, are created. Upon exposure of the phosphor particles to ionizing radiation (Fig. 10 provides an energy level diagram that illustrates this process), electrons are excited to a higher energy level (conduction band) and leave behind a hole at the $Eu2^+$ ion (valance band). While some of these electrons immediately recombine and excite the $Eu2^+$ to promptly emit, others are trapped at the F^+ centers to form metastable F centers, also known as color centers, from the German word "Farbe", which means color. The energy stored in these electron-hole pairs is the basis of the CR latent image and remains quite stable for hours. This mechanism has been disputed by some and supported by others; however, the end result is photostimulable luminescence.

6.6 *Processing the Latent Image*: When this phosphor (bearing the latent image) is subsequently exposed (that is, scanned with a laser as shown in Fig. 4) to a source of red light, most of the trapped electrons are "liberated" and return to the lower energy level (valence band) of the phosphor molecule causing PSL to be emitted. Figure 11 provides a simplified graphic illustration of this process that may be helpful in better understanding the fundamentals of this unique process.

6.7 *Residual Latent Image Removal*: Following a normal latent image process scan (see Fig. 4), all phosphors on the imaging plate must be further exposed to a high intensity source of white light in order to remove any remaining "residual" trapped

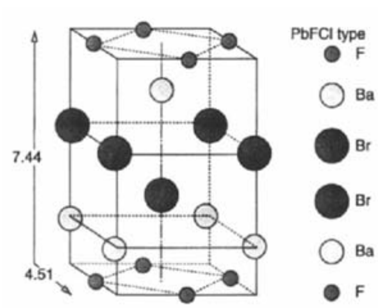


FIG. 8 BaFBr Crystal Structure

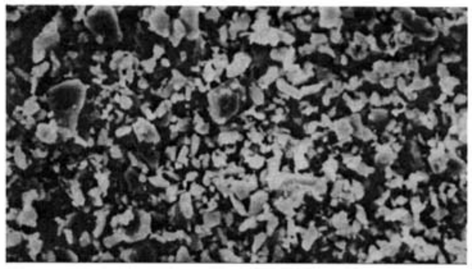


FIG. 9 Conventional BaFX: Eu Grains (10 microns)

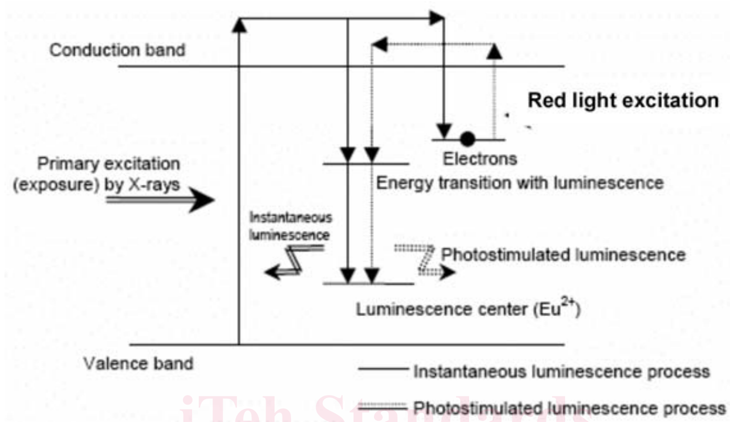


FIG. 10 Energy Level Diagram Illustrating Mechanism for Generating PSL in BaFBr: Eu^{+2} Crystal

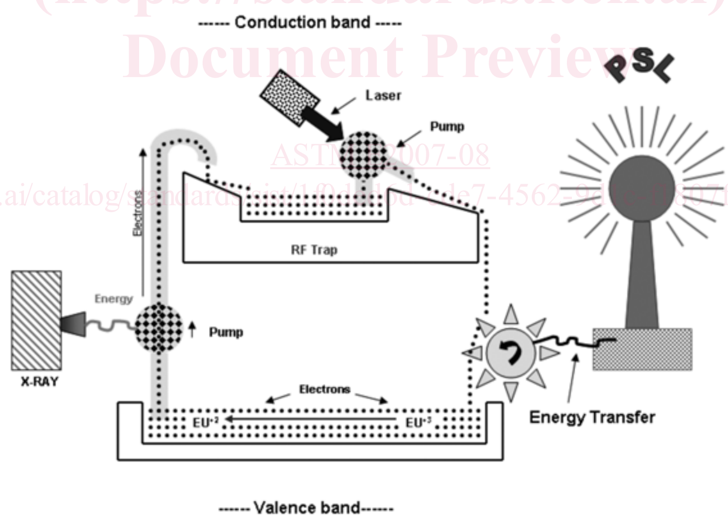


FIG. 11 Illustration of PSL Generation

electrons in the F centers. This process is referred to as an IP "erasure" and is usually performed subsequent to the IP scan and prior to any subsequent re-exposures of the IP. If an erasure cycle is not performed, an unwanted residual latent image may be superimposed on the next CR exposure if the IP is re-exposed soon after the first exposure. In the event no subsequent re-exposure of the IP is performed, any residual latent image (trapped electrons) will eventually fade as natural sources of red light energy (heat, etc.) cause remaining electrons to be liberated via the same physical process described above. Similarly, if erased IP's are stored near sources of radiation (background or other sources of ionizing radiation) an unwanted residual latent image (background) may develop within affected phosphors of the IP. Figure 12 illustrates a typical life cycle for the generation of PSL and PSL fading during exposure to X-ray radiation, followed by exposure to a high intensity source of "red" light. Since this process is primarily passive, the actual phosphor is often referred to as a "storage phosphor".

6.8 *CR Latent Image Issues*: Now that some of the fundamental physics of CR are established, we need to understand how this knowledge relates to everyday use and production of quality CR images. Most radiographers have a good understanding of the