CarestreamNDT

WHITE PAPER

Digital transformation is not a destination but a journey.

Going digital through CR, either at the lab or in the field.

INTRODUCTION

At Carestream NDT we want to share not only our technological developments and product portfolio, but also the knowledge and practical experience that our staff obtains by working shoulder-to-shoulder with customers like you. We aim to share this knowledge and experience in a straightforward fashion so that our readers may find practical applications in their everyday activities.

This series is directed but not limited to NDE professionals in the following industries: Oil & Gas, Nuclear, Construction, Foundry and Castings, Energy Generation, Aerospace, Transportation, Automotive, Military and Defense, Agriculture, Art Restoration & Museum Artifacts, and NDE Services Companies.

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Computed Radiography 101

Computed radiography (CR) is a non-film radiographic imaging process that uses reusable imaging plates (IPs) for radiographic image acquisition. ASTM E1316 "Standard Terminology for Nondestructive Examinations" defines CR as *"a two-step radiographic imaging process; first, a storage phosphor imaging plate (IP) is exposed by penetrating radiation; second, the luminescence from the IP's photostimulable luminescent phosphor is stimulated, detected, digitized, and displayed on an image display monitor".*

Photostimulable luminescence (PSL) constitutes the basis of CR.

PSL takes place when a halogenated phosphor compound emits bluish light when stimulated by a source of red spectrum light. The most common halogenated phosphor compound is europium-activated barium fluorohalide compound ($BaFX:Eu^{2+}$, where X may be a halogen atom such as Chloride, Bromide, Iodide.

Upon exposure of the phosphor particles to ionizing radiation, such as X-rays or gamma radiation, electrons in the phosphor compound are excited to orbit at a higher energy level and leave a hole at the Eu^{2+} ion. Some of these electrons immediately recombine and release PSL during the radiation exposure. However, many of the electrons and their respective holes (in the electronic configuration of the phosphor compound) remain trapped, creating a latent image. The energy stored in those electron-hole pairs remains stable for several hours.

Brian White, Research Scientist and Level III Radiographer at Carestream NDT, explains CR in the following terms[2]: *"CR phosphor plates capture X-ray and gamma electromagnetic radiation to store an electronic charge. Subsequently stimulated by a red laser, the plates release blue light proportional to the amount of exposure. This blue light is collected and converted into a voltage, which is then electronically sampled and processed to form the digital image."*

When an additional stimulus of high intensity white light is applied to the IP the remaining latent image is eliminated and the IP is ready to be reused to store a new radiographic image.

Understanding the components of a Computed Radiography System

CR systems have the portability to provide agile mobile image acquisition in field applications, but also have the versatility and flexibility to operate under the most demanding radiographic imaging laboratory environments with both flexible and rigid cassettes to hold IPs.

Regardless if they are used in field applications or in a Laboratory environment, we may distinguish four essential components of a CR system as is described in **Figure 1.** Examples of those components are identified in the images provided in **Figure 2.**

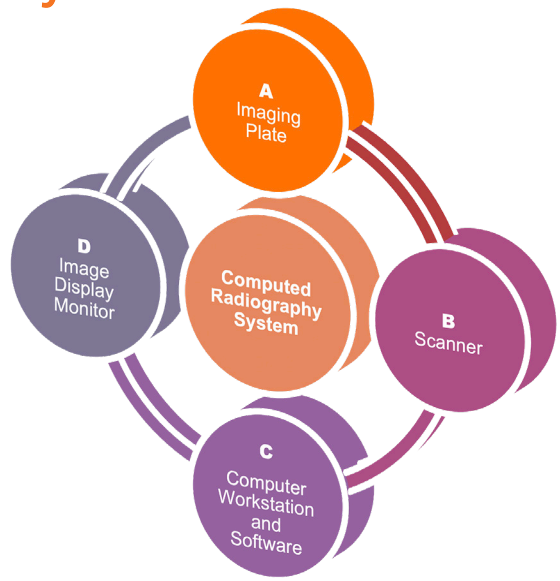
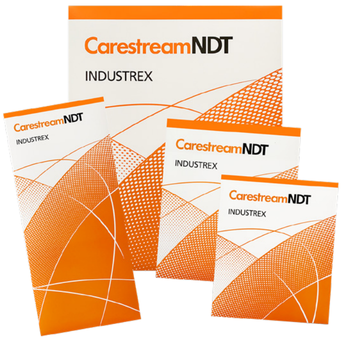


Figure 1: The four components of a Computed Radiogaophy System, Adapted from ASNT Nondestructive Testing Handbook, fourth edition: Volume 3, Radiographic Testing, [1]

Figure 2: Identification of componentes of a computed radiograophy system, in a fixed radiographic umaging laboratory environment (INDUSTREX HPX-1) and a field office (INDUSTREX HPX-PRO).

An overview of relevant characteristics of the four components



A Imaging Plates (IPs)

IPs operate similarly to X-ray film in that the radiation is captured by the IP and stored as a latent image in its phosphor layer. IPs are flexible and can be made in a variety of shapes and sizes, the most common being the same sizes as typical radiographic film dimensions. There are different types of IPs that have different brightness, much like film speed types.

An IP is made up of several layers including the phosphor layer; a flexible support, light-halation and backing layer; and a clear-top protective coating **(Figure 3)**. The support and light-halation layer are there to make the IP more dimensionally stable, less susceptible to creasing or damage, and to keep light from spreading during scanning. The phosphor layer is the active area that retains the latent image created during the radiation exposure. It is typically made up of phosphor grains combined with an adhesive or binding material, which is coated over the base material. A clear protective coating is then added to protect the phosphor layer from damage during use.

As it may also be perceived in the images of Figure 3, CR phosphor layers can be 10 to 40 times as thick as film emulsion layers.

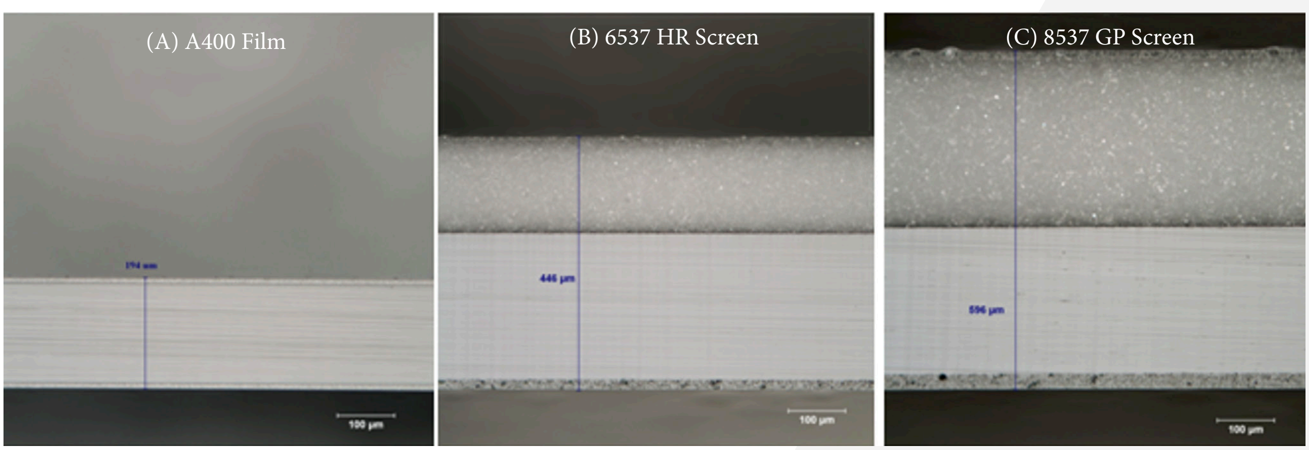


Figure 3: Thickness differences with optical cross sections of industrial film (A) versus industrial computed radiography imaging plates (B and C), from Brian White's Presentation "Imaging Plate Design and Use for Radiographic Nondestructive Evaluation" ASNT XVI Digital Imaging Conference 2013, [4]

A Imaging Plates (IPs) continued

Besides phosphor layer thickness, the size distribution of phosphor crystals **(Figure 4)** has an impact in achievable radiographic image quality. Brian White explains this effect in [4] *"Another key difference between imaging plate phosphors and film emulsions is that phosphor crystals have much wider particle size distributions. Figure 4 provides an example of one emulsion type versus one phosphor type. The wider particle size distribution of the phosphors results in additional light scatter. The additional light scatter and phosphor size further limit the achievable resolution and noise of the overall computed radiography system."* The impact of light scatter can be controlled; Brian shares his experience in this subject: *"Control and understanding of scatter is very important for CR IP use, and it is a key difference between IP and film applications. The use of beam collimation and intensifying screens to absorb low-energy radiation becomes critical for CR applications."*

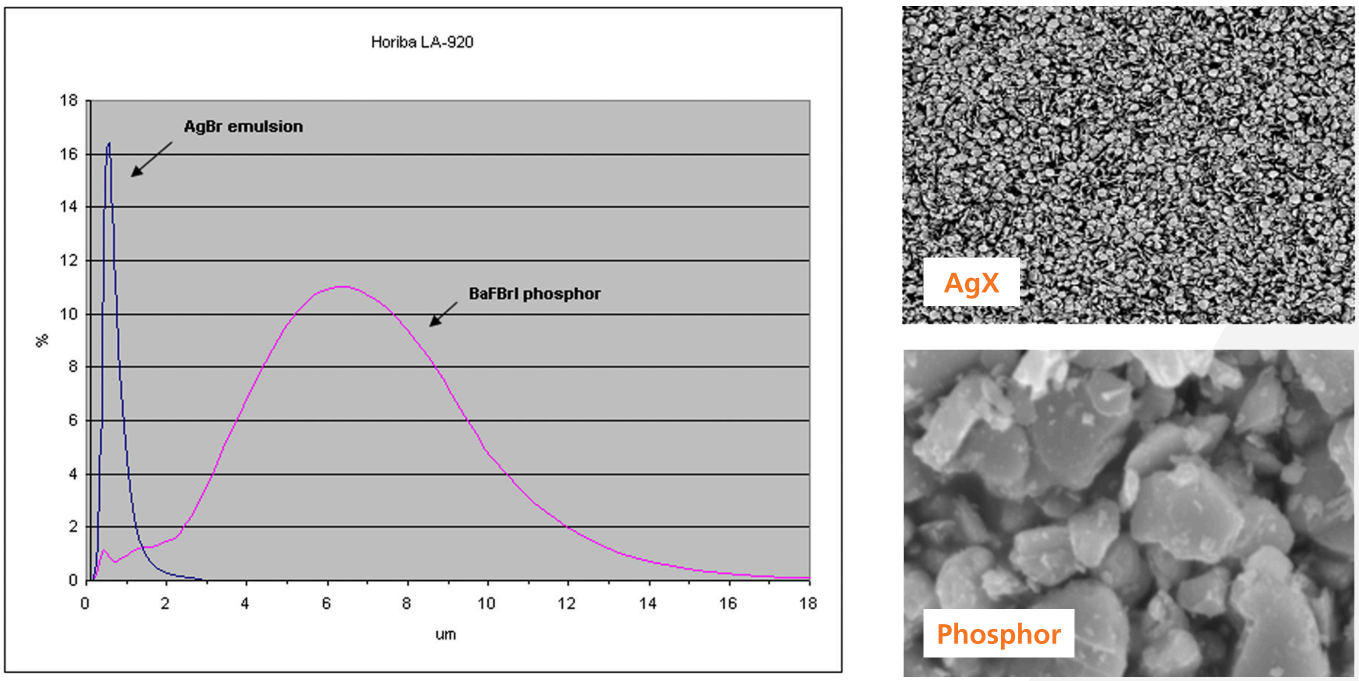


Figure 4: Particle size distribution of silver halide crystals versus phosphor crystals. From Brian White's Presentation "Imaging Plate Design and Use for Radiographic Nondestructive Evaluation" ASNT XVI Digital Imaging Conference, [4]

Carestream produces three types of IPs: standard resolution GP (green), HR (Orange) and high-resolution XL (Blue).

The characteristics of each type of IP type is based on the phosphor grain size, chemical compound, and color. These properties will determine the highest possible exposure speed and resulting resolution. **(Figure 5)**

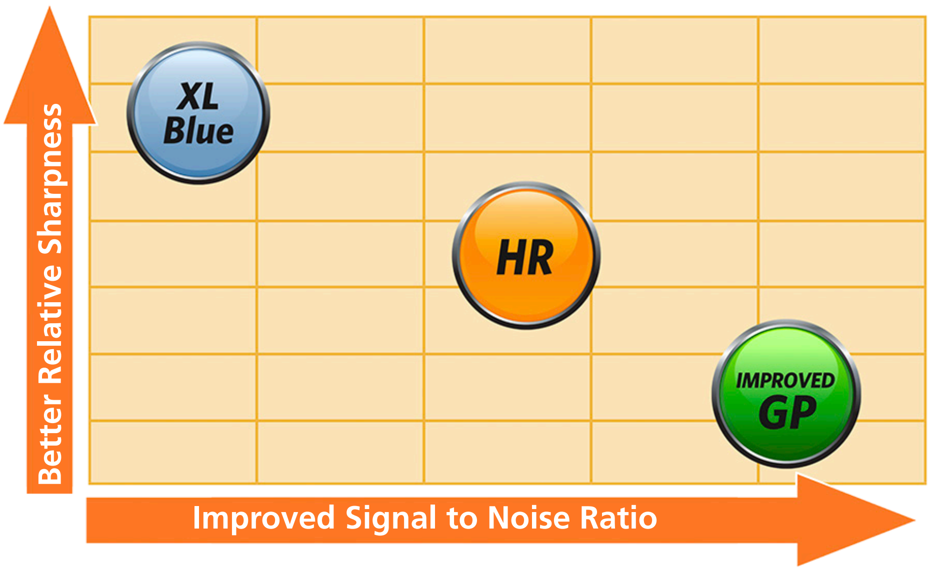


Figure 5: Relative image quality performance for industrial computed radiography imaging plates,adapted from Brian White's Article "Imaging Plate Design and Use for Radiographic Nondestructive Evaluation" ASNT XVI Digital Imaging Conference.

Table 1 provides a straightforward guide to select the proper IP type based in energy level and radiation type in order to contribute to obtain the best achievable radiographic image quality **(Table 1)**.

<table>
<tr><th>Radiation Source</th><th>Energy type</th><th>Energy Level</th><th>Plate</th></tr>
<tr><td>Linear Accelerators</td><td rowspan="4">X-Ray</td><td>2-15 MeV</td><td rowspan="2">GP</td></tr>
<tr><td>Betatron</td><td>2-10 MeV</td></tr>
<tr><td>Tubes</td><td>< 450 kVp</td><td>HR</td></tr>
<tr><td>Tubes</td><td>< 80 kVp</td><td>XL</td></tr>
<tr><td>Cobalt (Co60)</td><td rowspan="3">Gamma Radiation</td><td>Peaks at 1.17 and 1.33 MeV</td><td>GP</td></tr>
<tr><td>Iridium (Ir192)</td><td>Seven peaks between 200-600 keV</td><td rowspan="2">HR</td></tr>
<tr><td>Selenium (Se75)</td><td>Nine peaks between 66-401 keV</td></tr>
</table>

Table 1: Imaging plate selection guide as a function of energy level and energy types,adapted from Brian White's Article "Imaging Plate Design and Use for Radiographic Nondestructive Evaluation" ASNT XVI Digital Imaging Conference. [3]

B Scanner

Also called read-out unit or reader, is where the latent image is released from the IP Phosphor by stimulation from a red laser and collected for transmission to the computer for display. A red laser is rastered across the IP as it is transported through the scanner, releasing the PSL. The PSL light is then collected by a photomultiplier tube (PMT), processed through an analog-to-digital converter, and stored as digital pixel values (PVs) which are organized Into the X and Y coordinates of the image.

Carestream provides the INDUSTREX HPX-1 Plus Digital System, ideal for a lab environment where high-resolution is critical with adjustable PMT and laser power to fine tune every image for optimum capture and the INDUSTREX HPX-PRO Digital System, built for extreme portability into rugged imaging environments and improved productivity in field imaging applications, as is shown in **Figure 2.**

C Software and Computer Workstations

A CR system may be configured with one or more workstations. One workstation is suitable for portable in-field applications. When a CR system configured with two workstations, one may be used for image acquisition, while the second, or even a third, is used for image analysis. Networks can be configured as well, where several scanners feed images to multiple image analysis workstations. Our powerful all-in-one software INDUSTREX Digital Viewing Software enables customers to standardize on one software platform both CR and DR inspections needs.

D Image Display Monitor

Proper radiographic interpretation will require an image display monitor that can meet brightness, contrast, and resolution requirements of the code or standard used for the examination. The display monitor for image interpretation is a special piece of equipment and should not be taken lightly. Typically, a display monitor with the minimum brightness at maximum digital driving level (DDL) of 250 cd/m2 or greater, and a minimum contrast of 250:1, may be acceptable for use by most codes or standards. The display monitor should be appropriately sized for the expected radiographic image sizes that will be routinely reviewed.

There is also a difference between imaging grade and commercial-grade display monitors. A commercial-grade display monitor is usually set at much lower brightness and contrast levels than a (medical) imaging-grade display. A commercial-grade display's backlight will fade over time whereas an imaging-grade display has a feedback circuit that constantly adjusts the backlight to maintain its brightness and contrast for the life of the device. There is also the choice between using a color or black and white display monitor. With a color display monitor, black is created with 3 colors; red, green, and blue, and it is not a true black. With X-ray film however, the base is a very light blue to help with eye strain, so it's not an issue to use either black and white or color for the display. Components C and D may be integrated into a single portable laptop computer for field or laboratory environments.

As we explained in the first white paper of this series, obtaining an adequate radiographic image quality is the result not only of the science principles that sustains the radiographic imaging process but also from the craft and experience that the radiographer put into function while defining an adequate radiographic technique. In the case of CR, factors inherent to the characteristics of the four components affect radiographic image quality.

In the case of computed radiography – besides the traditional factors associated with film – radiographic techniques such as source to object distance or geometric unsharpness, new factors such as scanning resolution, pixel intensity, signal-to-noise ratio (SNR), or contrast-to-noise ratio (CNR) shall be taken into account.

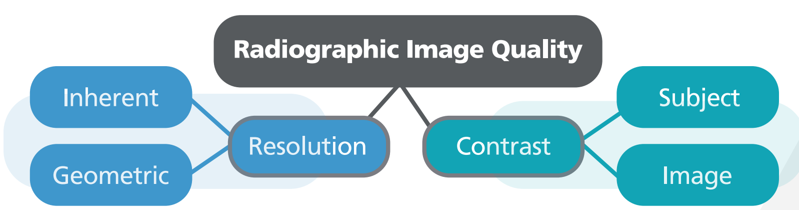


Figure 6: Factors inherent to CR systems that affect radiographic image quality, from ASNT Nondestructive Testing Handbook: Volume 3, Radiographic Testing 4th Edition [1]

Advantages and limitations of computed radiography

Chapter 8 of the most recent edition (4th) of ASNT Nondestructive Testing Handbook: Volume 3, Radiographic Testing highlights **(Table 2)** the most important advantages and limitations of transitioning from film to CR. Table 2 lists some of these advantages and disadvantages as follows:

Advantages	Limitations
1. Because CR is considered a film replacement technology, it is easily incorporated into the (regular) radiographic process flow with minimal changes. 2. Soft cassettes can be used allowing the IP cassette to be wrapped around products such as pipes and tanks. 3. Hazardous waste in the form of film processing chemicals is eliminated. 4. IP sizes match most available film sizes and can be cut to specific shapes and sizes, just like film. 5. Scan resolutions have improved over recent years and CR can scan IPs at 100, 50, and 25 µm, which provides better resolution than many other radiographic inspection methods without geometric magnification. 6. Since CR images are 12 bits or higher, the material thickness range that can be imaged in a single exposure is often much higher than with film. This is particularly advantageous with parts such as castings, where a single digital radiograph can be used to replace multiple film speed loads used for the same view. In this case, image interpretation time may be significantly reduced.	1. IPs have a limited life so handling artifacts, such as scratches and crimp marks, are especially detrimental to image quality and must be meticulously controlled. Since the photostimu-lable phosphor in the IP is hygroscopic, surface scratches that penetrate the protective surface layer may allow water or moisture damage to the IP. 2. Image sizes can be larger than a DDA-generated image due to higher pixel densities. For example, a 25µm, 35.56 x 43.18 cm (14 x 17 in.) IP versus a 200 µm, 40.64 x 40.64 cm (16 x 16 in.) DDA. 3. When IPSs are cut to special shapes, if the edge of the cut is not (properly) sealed, phosphor particles may flake off and contaminate the scanner, causing image artifacts.

Table 2: Advantages and limitations of CR processes. Adapted from ASNT Nondestructive Testing Handbook, fourth edition: Volume 3, Radiographic Testing [1]

The principles and paradoxes of imaging plate design

Brian White provides his advice to obtain the greatest sensitivity with IPs in [4] *"The imaging plate type can help determine the achievable image quality. The imaging plate response is influenced by the phosphor size, phosphor size distribution, and the chemistry of the individual phosphors in the plate. The imaging plate layer structure, placement, and phosphor thickness also help influence the final image quality characteristics. Tradeoffs exist between speed (brightness), granularity (noise), and sharpness. A paradox exists for the plate designer. With film, as sharpness is improved, the granularity also improves at the expense of speed. With plates, as the sharpness is improved, the noise gets worse and the brightness is decreased.(…) The greatest sensitivity will be achieved with the minimum power to penetrate the specific material thickness and type."*

How you can use the information of this document in your everyday activities

For our readers interested in the explore how computed radiography (CR) can be integrated to your processes: **https://www.carestream.com/en/us/nondestructive-testing-ndt-solutions**

Here are some supplementary information resources from Carestream's products and services portfolio:

Products Featured:

- INDUSTREX HPX-PRO Digital System
- INDUSTREX HPX-1 Plus Digital System
- FLEX GP, FLEX HR and FLEX XL Blue Digital Imaging Plates
- INDUSTREX Digital Viewing Software

Training Services:

- **Advanced Industrial Radiographic Training Academy**
  Computed Radiography - 40 Hour Online Course
  Digital Imaging - 40 Hour Classroom Training

Resources from ASNT:

- Nondestructive Testing Handbook, fourth edition: Volume 3, Radiographic Testing: https://www.asnt.org/Store/ProductDetail?productKey=83ea27b3-d68f-483d-9354-e447ef2b3915

References:

1. ASNT, (2019), Nondestructive Testing Handbook, fourth edition: Volume 3, Radiographic Testing, Chapter 8, Pages 259-276 Columbus, OH, American Society of Nondestructive Testing.
2. ASTM (2021), ASTM E1316 – 21a, Standard Terminology for Nondestructive Examinations, West Conshohocken, PA, ASTM International, 2020. <
3. White, B., Article "Imaging Plate Design and Use for Radiographic Nondestructive Evaluation" ASNT XVI Digital Imaging Conference July 22 of 2013.
4. White, B., Presentation "Imaging Plate Design and Use for Radiographic Nondestructive Evaluation" ASNT XVI Digital Imaging Conference July 22 of 2013.