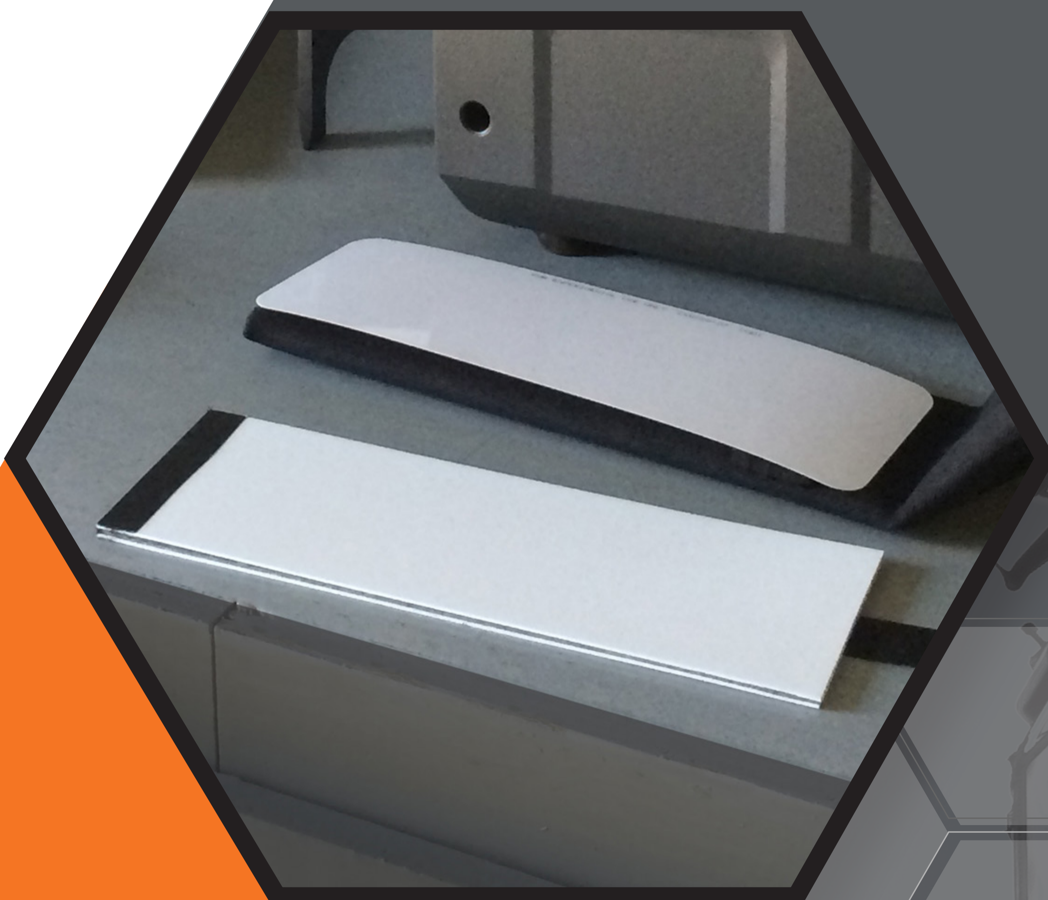
Carestream NDT

WHITE PAPER

Imaging Plate Use for Radiographic Non-destructive Evaluation.

Best practices directed to achieve the best quality image possible derived from our hands-on practical experience.



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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The utilization of computed radiography (CR) systems for digital radiography requires a higher level of training and knowledge relative to film radiography. Computer skills and digital technologies usage competencies are required to achieve the desired results. Imaging plates (IPs) are a core component of any CR system. Imaging plate selection has a major impact on image quality. Likewise, a deeper understanding of how to expose the plates, control scatter, handle the plates, utilize proper reader settings, and use of available image processing will make a significant difference in the results achieved. Over time, imaging plates used for many cycles may develop imaging artifacts from a variety of sources. The recommendations and guidelines presented in this white paper will help you achieve both the best image quality possible and maximum plate lifetime, which translates into a reliable and sustainable CR process.

The conversion from film to digital imaging has already happened across most imaging industries, particularly in health-related disciplines. A 2D digital image in industrial radiography, either CR or DR, is actually an array of rows and columns of numbers that represent shades of grey. For negative working systems, the pixel representation increases linearly from white to grey to black. Digital imaging offers many advantages, such as the ability to adjust contrast and brightness, zoom, apply image processing algorithms (including artificial intelligence (AI) assistants for image analysis), annotate images, do calculations, store electronically, and easily share images across computer networks. In many cases, users can see defects more easily with digital technology because of improved system contrast sensitivity. In industrial environments, the conversion of imaging processes from film to digital has been slow because a higher level of knowledge and training is required to utilize digital technology. The agility of conversion from film to digital varies not only from the technology adoption dynamics and the nature of the regulations applicable to each specific industry, but also is affected by the specific characteristics of a geographic region such as the technological evolution of the local industrial ecosystem, availability of properly trained individuals, and the restriction of national and local regulations.

Imaging Plates 101

Brian White, Research Scientist and Level III Radiographer at Carestream NDT, explains the fundamental physical principles that support the use of imaging plates in industrial radiography in the following terms[13]: *"Imaging plates utilized for computed radiography function as imaging detectors. They capture and store energy from the radiation beam (typically X-ray or gamma rays), and they convert that stored energy into blue light through a process called photo-stimulated luminescence. Film is also an imaging detector, whereby electrons from lead intensifying screens fluoresce and expose the film to create a latent image. Likewise, flat panel digital detector arrays are imaging detectors, where the photodiode array captures light from a scintillator that has been stimulated by radiation and thin film transistors store the charge. The selection of an imaging plate has a major role in determining the achievable image quality from a computed radiography system. Films have different speeds, granularity, and resolution. Likewise, imaging plates are characterized according to their resolution capability.*

High-resolution plates have lower brightness and higher noise, whereas lower-resolution imaging plates have higher brightness and lower noise. The pixel intensity response of the imaging plate is linearly dependent upon the radiation dose that it receives. Additionally, scatter must be well controlled to achieve acceptable contrast sensitivity and overall image quality. Imaging plates have physical properties that are remarkably similar to film. However, imaging plates are used for many cycles, and over time they develop scratches and abrasions that manifest as imaging artifacts. Other factors can also contribute to image artifact formation. How well the imaging plate resists artifact formation is dependent upon plate durability. To further complicate matters, how a radiographer uses an imaging plate determines what artifacts are seen and when. This white paper discusses usage criteria and guidelines for optimum image quality and minimized artifact formation for computed radiography systems."

An expanded vision of computed radiography imaging processes

Imaging plate selection helps determine the image quality that can be obtained from a computed radiography system. The probability of detection is influenced by the five factors listed in **Figure 1**.

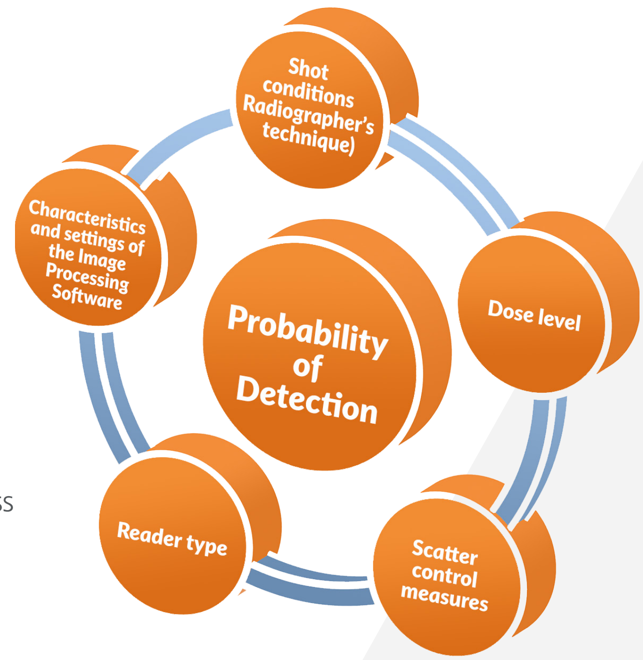
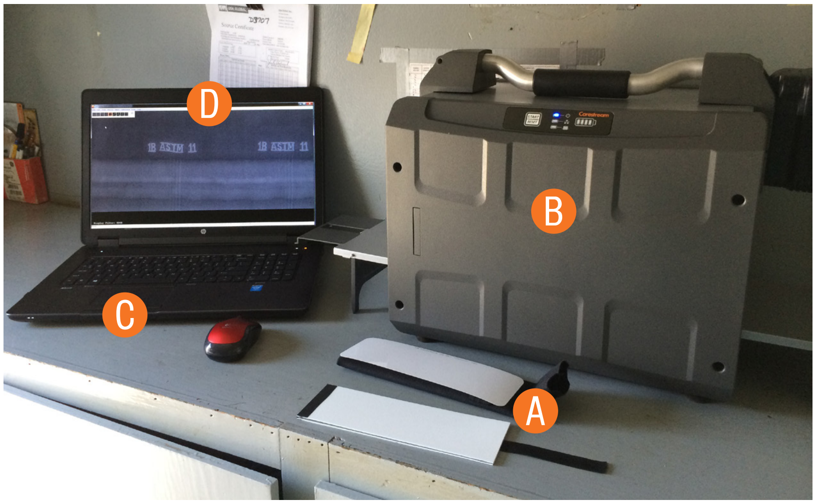


Figure 1: Factors that Influence the Probability of Detection in Radiographic Imaging Processes, based on White [7] [8].

The physicist Stephen Hawking, while he was in the process of publishing his first book devoted to a general audience, was advised that any equation included in his text will diminish the number of potential readers in half. He took the risk to include just one equation (E=mc2, Einstein's mass–energy equivalence equation) because this equivalence notion was fundamental to explain the content included in the scope of its book. We will, similarly, take some risk with the potential readers of this article, and will include just one equation that will be fundamental to explain several of the ideas discussed in this article. This equation, which explains the interconnection of three key image characteristics – brightness, sharpness, and noise – that have a profound effect on image quality (IQ), is as follows:

$$IQ = \frac{(\text{brightness}) \times (\text{sharpness})^2}{(\text{noise})}$$

The equation explains that image quality: 1) is directly proportional to the brightness, which means that as brightness increases, within the limits that allow proper image interpretation, the image quality also increases, 2) is directly proportional to the sharpness but in this case, the value of sharpness is squared, which translates into a sensibly deeper impact of increased sharpness in image quality than the influence of brightness, and 3) is inversely proportional to noise, which translates that as noise decreases image quality improves in a linear form. In brief, as brightness and sharpness improve, and noise is reduced, the overall image quality improves.



A CR system includes the A) detector (imaging plate), B) the reader, C) a computer, its associated imaging processing software, D) and a monitor. The detector captures the radiation. The reader extracts the stored charge from the imaging plate by stimulating the phosphors with red laser light. The plate glows blue when the red laser strikes it. The blue light is collected and converted into a voltage signal that is then sampled and sent to the computer. The computer assimilates the voltage data into rows and columns that correspond to specific plate locations. The voltage signal is then mapped to various intensity levels for the individual pixels. Using specific software, the user then can view the analog representation of the digital image on a monitor. We strongly encourage the reader to review our white paper *"Throwing light over Computed Radiography myths through sound and practical Imaging Plates information"* for more details on the elements that constitute a CR system.

There are some general guidelines that one can follow to obtain optimum CR image quality. For a given part, the radiographic technique and exposure conditions can closely match a film technique. Typically, a radiographer uses the minimum kV during exposure that penetrates the material to a specified thickness; this maximizes the contrast sensitivity. The mA (tube current) and time can be changed to modify the overall dose level needed. For radioisotopes, the source energy is fixed and the only thing that can be varied is the exposure time for a specific activity. With CR, the imaging plates are very responsive to dose. Therefore, the easiest way to improve image quality is to increase the dose. The system grey level response will be linear as a function of the dose level.

The selection of imaging plate type also determines image quality. **Table 1** provides general guidelines for imaging plate selection based on energy levels and energy type used for a truly diverse set of radiographic techniques:

Radiation Source	Energy Type	Energy Level	Plate
Linear Accelerators	X-ray	2 – 15 MeV	GP
Betatron	X-ray	2 – 10 MeV	GP
Tubes	X-rays	<450 kVp	HR
Tubes	X-ray	<80 kVp	XL
Cobalt 60	Gamma	Peaks at 1.17, 1.33 MeV	GP
Iridium 192	Gamma	Seven peaks between 200 – 600 keV	HR
Selenium 75	Gamma	Nine peaks between 66 – 401 keV	HR

Table 1: Imaging plate selection as a function of energy level and energy type, adapted from White [9].

*General purpose (GP) imaging plate*s have lower resolution capabilities, but they are brighter and have slightly less noise. These plates typically are used for very high-energy applications or when image quality is not particularly critical. *High resolution (HR) imaging plates* offer the best combination of resolution, brightness and noise. These typically are used for applications where one desires the best possible image quality. *Ultra-high resolution (UHR) imaging plates* resolve fine detail because they have blue dye added to the phosphor layer to absorb the scatter from the red laser. However, they have reduced brightness and higher noise levels. These plates typically are used for lower energy applications and for materials that have less attenuation.

Another important attribute to control during CR exposures is Compton scatter. Scatter is the formation of longer wavelength, lower energy radiation as it interacts with the material being irradiated. Computed radiography plates have high absorption at lower energy levels. Lead screens on the backside of the imaging plate typically are used to control scatter. Sometimes, a thin sheet of copper is placed between the lead and the back side of the imaging plate to block the fluorescence of the lead. When energy levels are high, typically above 200 kV, a front-side lead screen may be used for additional scatter control. Table 2 offers some suggestions to start exploring suitable alternatives of screens and radiographic techniques to minimize the effect of scattered radiation on image quality.

Energy Range	Front Screen, inches	Front Screen, mm
> 5MeV	0.020 to 0.150 Fe, Cu or Pb	0.6 to 4.0 Fe, Cu or Pb
> 1 to 5 MeV or Co-60	0.010 to 0.030 Fe or Cu, plus 0.020 to 0.040 Pb	0.3 to 0.8 Fe or Cu, plus 0.6 to 2.0 Pb
Ir-192 or Se-75	0 to 0.020	0 to 0.4
≤ 1 MV and > 250 kV	0 to 0.010	0 to 0.3
≤ 250 kV and > 50 kV	0 to 0.005	0 to 0.1
≤ 50 kV and > 0 V	None	None

NOTE 1 – The screen thicknesses listed for the various energy ranges are recommended thicknesses, not required thicknesses. Other thicknesses and materials may be used provided the radiographic quality level is achieved.

NOTE 2 – Screens are Pb unless otherwise indicated.

NOTE 3 – Pb screens may be replaced completely or partially by Fe or Cu screens. The equivalent thickness for Fe or Cu is three times the thickness of Pb.

NOTE 4 – If necessary, the IP should be shielded from backscattered radiation by a sheet of lead of at least 0.010 in. [0.254 mm] thickness or a sheet of tin of at least 0.060 in. [1.5 mm] thickness, placed behind the IP. An additional shielding of steel or copper of 0.005 in. [0.127 mm] should be applied between the lead shield and the IP to reduce the influence of lead X-ray fluorescence radiation. No lead screens should be used in contact with the back side of the IP for radiation energies above 80 keV.

Table 2: Metallic Screen Recommendations for CR Imaging Processes, adapted from ASNT [1] and White [8].

ASTM E2033-17 offers specific guidance for Scattered Radiation Control in the following terms: *"Metallic screens (front, back, or both) or filters should be used as necessary to control scattered radiation from the floor, walls or other surrounding objects from interfering with the image or radiographic image quality requirements. Additionally, scattered radiation effects can be reduced by collimating the radiation beam as much as possible to the area of interest (AOI)".*

Between exposure and reading, imaging plates lose signal as a function of time. The signal loss is a result of photoelectrons recombining to non-useful energy states. The signal declines naturally as a function of time; this decay process is called dark decay. The signal also declines due to light fading, which is caused by handling bare plates in lighted room conditions between exposure and scanning. Background lighting further stimulates the recombination of photoelectrons to non-useful energy states. *The background lighting condition recommendation between exposure and reading is 2500 lux-seconds or less. To improve consistency, it is recommended to read the plate within five minutes after exposure. Implement IP manufacturer's directives related to environmental conditions in the areas where IPs are handled and processed; this includes the selection of the adequate type of lighting and the use of protective gloves to maximize the IP lifespan, minimizing the possibility of artifacts due to inadequate handling.*

The reader type and settings also determine image quality. The reader is an assembly of hardware, optics, and electronics. All readers have roughly the same functionality. The mechanism of image formation follows the process of photostimulated luminescence, whereby a red laser stimulates the phosphors in the imaging plate to emit blue light in proportion to the dose that was received. *Important reader parameters that impact image quality are the pixel size selection, the laser intensity, and the spot size.* Equilibrium is fundamental in choosing those parameters. A fundamental rule of thumb is to review, as a starting point, which values of these three parameters are commonly used in the industry for the CR imaging application you are attempting, within the acceptable ranges of the applicable CR codes, regulations and/or standards for the components you are analyzing, and from this starting point, use the suggestions included along the present white paper to improve image quality.

The analog representation of the digital image is displayed on a monitor. It is essential to always have in mind that *image quality calculations are done on the captured data; not on the analog data from the monitor.* Software is used to view and manipulate the image for viewing. Proprietary image processing can be performed to enhance either the display or the underlying data. *The monitor should meet the required recommendations for brightness and contrast ratio suggested by the CR equipment manufacturer, and the image should be viewed under the appropriate background lighting conditions and viewing distance as specified in ASTM E2033-17 paragraph 7.16.*

Best practices of CR imaging processes using imaging plates

Hole or wire type image quality indicators are used to ensure that the appropriate contrast sensitivity is being met for individual exposures. ASTM E2445 specifies that *the key image quality metrics are contrast sensitivity, basic spatial resolution, and signal-to-noise ratio.* The contrast sensitivity is the minimum percent change in an object that produces a perceptible change in the image. A radiographer should discern the smallest possible difference in thickness in order to perceive defects **(See Figure 2)**.

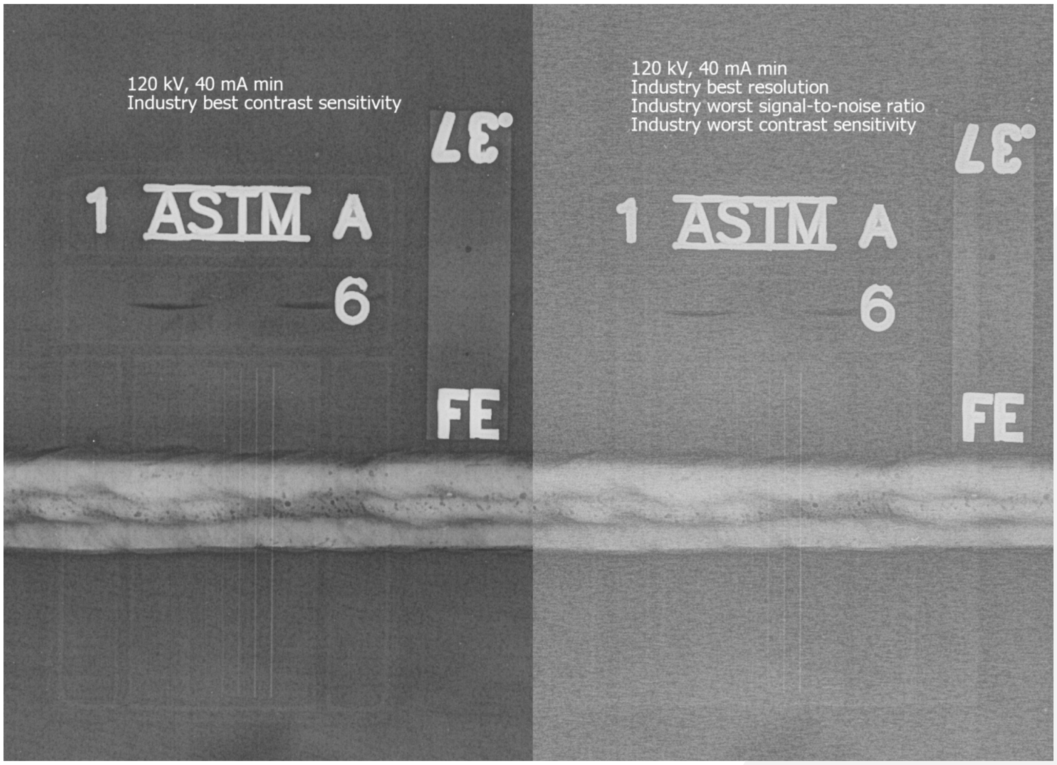


Figure 2: The visible impact of contrast sensitivity, spatial resolution, and signal-to-noise ratio on CR image quality, from White [7] [8].

Typically, as described in ASTM E1647, we desire 2% contrast sensitivity or better for the material type that we are examining. The basic spatial resolution is a measurement of the amount of detail in the image, typically measured on an image of a duplex wire gauge. Better resolution (higher detail) is usually desired, though not always necessary. The basic spatial resolution is a function of the system pixel size, laser, imaging plate, and radiographic conditions. The signal-to-noise ratio (SNR) is a calculation of mean pixel intensity divided by the standard deviation (noise) of a region of interest.

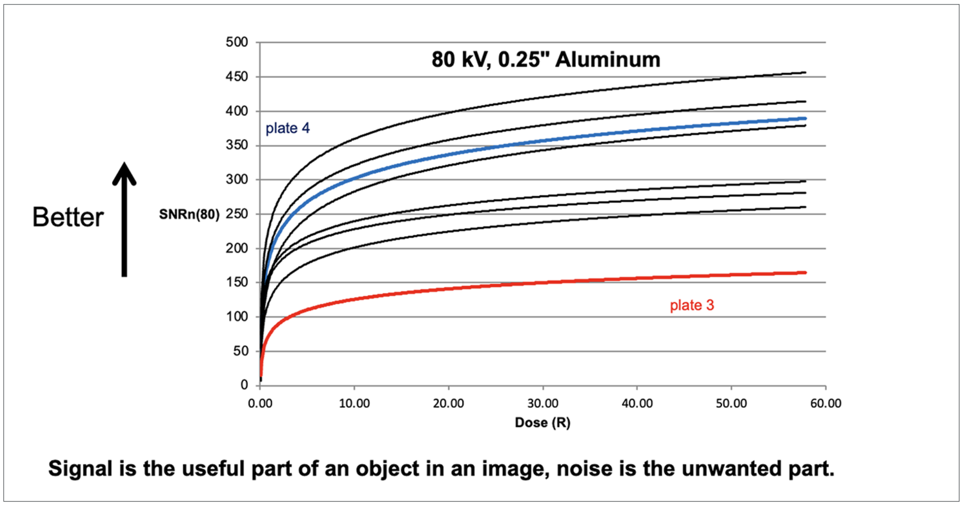


Figure 3: The effect of Dose Level on the signal-to-noise ratio values for the images described in Figure 2, from White [7] [8].

Figure 3 illustrates the signal-to-noise ratio normalized to a basic spatial resolution of 80 µm (SNRn(80)) as a function of dose level for an HR plate in a typical CR system. As the dose is increased, the normalized SNR rapidly improves and then levels off. The plate in Figure 1 was exposed at 80 kV and the SNRn(80) was plotted for a 0.25" thickness of aluminum.

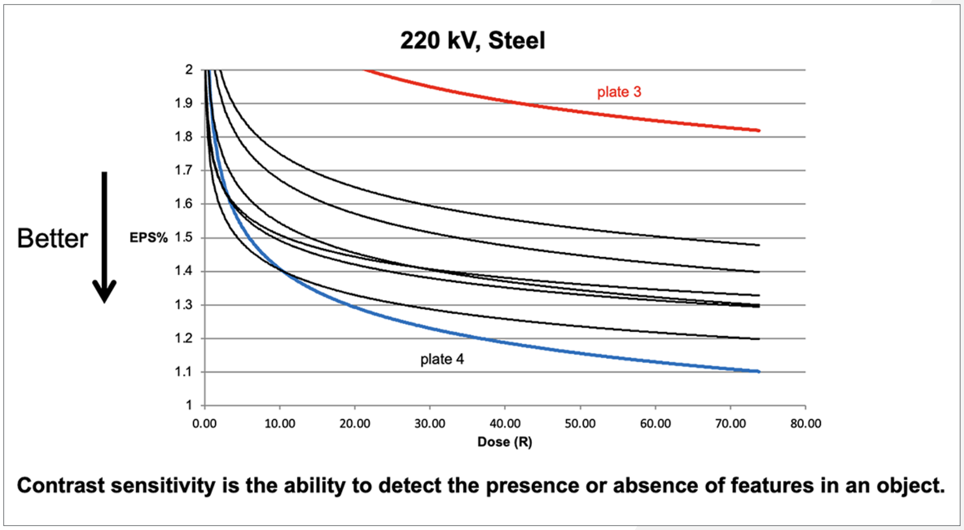


Figure 4: The effect of Dose Level on the equivalent penetrameter sensitivity (EPS) contrast sensitivity for the images described in Figure 2, from White [7] [8].

Figure 4 illustrates the equivalent penetrameter sensitivity (EPS) contrast sensitivity as a function of dose level for an HR plate in a typical CR system. The EPS technique for determining an estimate of contrast sensitivity is described in ASTM E2446. As the dose is increased, the contrast sensitivity rapidly improves and then levels off.

Imaging artifacts are another aspect of examination that radiographers have to contend with. ASNT's Nondestructive Testing Handbook, Fourth Edition, Volume 3 - Radiographic Testing defines Artifacts or false indications as (1) Test indications that could be interpreted as originated from a discontinuity but that actually originates where no indication exists, and (2) Indications due to misapplied or improper testing. By its definition it is evident that all NDE methods and techniques are subject to be affected by false indications, therefore imaging artifacts may be present in radiographic images, regardless if the recording media is film, imaging plates or DDAs, and generate the need of repeating certain images where artifacts interfere with image interpretation. Artifacts are caused by the interaction of the reader's laser with the imaging plate surface. ***Artifacts are typically white in the radiographic image because they are light blocking.*** Ideally, an imaging plate would have sufficient durability to allow for repeated use without imaged artifacts. ***An imaging plate is no longer usable when a radiographic artifact can potentially hide an indication, therefore rendering the plate unsuitable.*** The number of achievable use cycles is dependent upon the operating environment and the user's tolerance for artifacts. Protective overcoat technology is the primary driver for improved imaging plate lifetime.

Durability relates to the material physical properties of the imaging plate; specifically, the material properties of the overcoat that protects the phosphor layer. ***Scratch and abrasion resistance, dust repellency, the ability to clean, moisture and chemical resistance, crack avoidance, and edge integrity are examples of durability attributes.*** Scratches and abrasions both create radiographic image artifacts, but they form differently.

Scratches form from very fine localized pressure dragged across a prescribed distance. Figure 5 utilized a 47° conical sapphire stylus with a 62.5 µm radius conical tip to create the scratches. Constant loads of 3, 5, 10, 25, and 50 g were applied to create the scratch tracks. Loads less than 25 g did not image in the flat field radiograph.

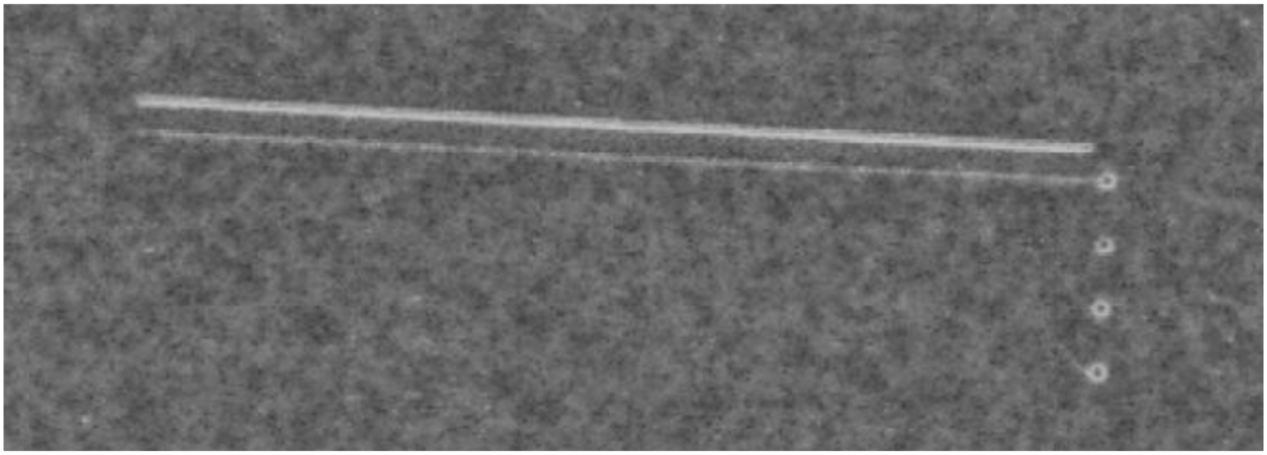


Figure 5: Constant load scratch test with sapphire stylus., from White [8].

Dust particles can become attracted to the surface of a plate. The particles will cause the red laser to deflect, or will block blue light, which shows as tiny white spots in the image. The best way to manage dust particles is to use an electrostatic roller to clean the plate surface prior to scanning. The ability to clean the surface is important in order to remove dirt or debris that may form over time. Another source of artifacts can be moisture or oxidizing chemicals. The phosphor contains iodide, which can be converted to iodine. Iodine is yellow and blocks blue light, which manifests as image artifacts. Water, peroxides, and ozone gas can form artifacts in contact with the imaging plate surface. Cracks or edge chipping can result in artifacts; however, plates are designed to minimize these cracking and chipping issues.

There are usage criteria and guidelines for maximizing imaging plate lifetime. When not in use, store plates flat in dark and dry conditions. Handle them by the edges and use cloth gloves if desired. Do not crease or kink the plate because this will form a permanent and irreversible crack. Avoid extreme humidity and or wet conditions when using an imaging plate. Avoid surface temperatures greater than 212 °F (100 °C); and use plates in the temperature range of –22 to +120 ºF (–30 to 49 ºC). For surface cleaning, use only the manufacturer-recommended cleaner with a lint-free cloth. In customer use situations there are handling guidelines that maximize plate lifetime. Avoid sliding the plate surface against abrasive materials. For high energy conditions such as iridium radioisotopes that require front side leads, completely open the cassette before insertion or removal of the plate. Do not remove the protective overcoat of the lead, as lead dust on the plate surface will form imaged artifacts.

Where can I innovate in my everyday work? Guidelines to achieve optimum CR image quality.

The importance of having sufficient dose on the image capture media or device (regardless if it is film, imaging plate, DDAs) to obtain optimum image quality cannot be overstated: Dose is it at the core of the image-forming signal received. Without sufficient dose, the remaining inherent noise in the system becomes an ever-increasing part of the final image. Noise is non-image-forming signal and, in consequence, it is not a radiographer’s friend. Admittedly, in NDT applications, exposure times may be long and sometimes this is perceived as having a negative impact on the process productivity, but it is shortsighted to under-expose an object to end up with less than optimum quality in the resulting images. To support key decision-making processes and actions, image quality is what matters. **Table 3** compiles key elements that can have a positive impact on your everyday CR imaging practices using IPs:

Best practices in Computed Radiography Imaging Processes	
Summary of the key ideas in this White Paper	Remember that sharpness is not the best indicator of image quality; IQ is a function of brightness, sharpness, and noise; all three work together.
	Imaging plate selection, dose level, and scatter control determine the radiographic image quality for computed radiography.
	Plate handling and use determine the artifact level in the radiograph as a function of time; this results in how many use cycles can be achieved.
	Follow best practice guidelines above to maximize the overall image quality and the number of imaging plate use cycles.
General guidelines to handle IPs	Good radiographs are images that are free from artifacts!
	IPs should be handled as gently and carefully as possible, taking care not to scratch or contaminate them, which means also proper handling, cleaning and maintenance of CR cassettes and screens. If you follow the following guidelines, IPs can easily provide the expected plate life for the customer and be utilized for many cycles.
	Regularly clean the IP using a dry soft, lint-free cloth, such as a microfiber towel; if soil cannot be removed by dry wiping, use manufacturer's approved IP cleaning materials.
	After wet wiping, lightly wipe the IP with a soft, dry cloth. The IP must be dried completely before being reloaded into a cassette.
	It's critical to handle IPs with care to avoid damaging them. Avoid using plastic erasers or any solvents that are not approved, and refrain from using your fingernails to scratch or dig into the surface of the IPs.
	IPs should be handled in such a way to avoid crimping.
	Do not bump IPs against other objects and do not drop them onto the floor or the top of a table.
	Anything that blocks light at the surface of the IP will manifest as white spot artifacts in the image.
	An imaging plate is no longer usable when an artifact can potentially hide an indication in the radiography's zone of interest.
	The number of use cycles for the IP is determined by the artifact level and the tolerance for artifacts.
	When IP artifacts, such as crimp marks, scratches, or others, cause the IP to be unusable, the IP should be removed from service and disposed of in accordance with the manufacturer's recommendations. Most IPs will have a Material Safety Data Sheet (MSDS) available from the manufacturer.
Guidelines to achieve optimum CR image quality	The CR radiographic technique can closely match the film technique.
	The best way to improve image quality is by increasing dose.
	Scatter must be controlled to achieve the best possible image.
	The pixel intensity must be related to an image quality level.
	Select the proper imaging plate for your application.
Guidelines to prevent artifacts in Computed Radiography Imaging Processes	Store IP in dark and dry conditions; avoid extreme humidity or wet conditions.
	Handle by the edges and use gloves to avoid fingerprints; use manufacturer-recommended cleaner with a lint-free cloth.
	Do not crease, kink, or drag across surfaces.
	Avoid surface temperatures > 212 F (100 C)
	Temperature range for use; -22 F (-30 C) to 120 F (49 C)
	Completely open flexible cassettes before insertion or removal of a plate when front side leads are used.

Table 3: Best practices in Computed Radiography Imaging Processes, adapted from White [7] [8].

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

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

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

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Resources from ASNT:

- Nondestructive Testing Handbook, fourth edition: Volume 3, Radiographic Testing: https://source.asnt.org/1pekc1o/

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8. White, B., (2015) Presentation "Imaging Plate Use for Radiographic Nondestructive Evaluation" ASNT 2015 Annual Conference.

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