



How to evaluate the radiographic performance and long-term stability of a computed radiography system

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Abstract

The fundamentals of Computed Radiography (CR) are well established (ASTM E 2007 and E 2033), but until recently, there were no comprehensive, formal methods for evaluating the full range of the radiographic performance characteristics of a CR system. Such measures and periodic monitoring are important in assuring optimum and consistent quality of CR systems. This paper will highlight some useful measures and will assist users in accordance with ASTM E 2445, “Standard Practice for the Qualification and Long-term Stability of Computed Radiology Systems,” ASTM International.

1. Introduction

There are many measures that could be considered for CR systems, but this paper will keep the list manageable and focus on the primary areas of interest. System performance can be divided into two categories:

1. The response characteristics of the imaging plate (IP), and,
2. The cascaded performance of the IP response with the characteristics of the CR reader hardware.

Note that this is a simplification because an IP can't be evaluated without a CR reader, nor can a CR reader be evaluated without an IP. Given that the response characteristics of the IP are largely a function of the properties of the plate itself and constant from a system perspective, this paper will not focus too much on its evaluation and periodic monitoring from a user standpoint. It is critical, however, to understand the response of the plate to the exposing environment and to establish a good baseline technique from which to monitor system performance.

A primary concern in exposing storage phosphor imaging plates is their keen response to low-energy radiation, as this is where scattering occurs and can have a detrimental effect on image quality. This, while certainly dependent on the specific IP in use, is also a matter of physics, in general, and will pertain to CR performance in a broad sense. It is less dependent on the specific CR reader hardware employed. Controlling this scatter to produce an optimum exposure will minimize those effects that are more a matter of physics and allow a more accurate look at the system parameters, which may degrade over time and, thus, are more of interest from a monitoring standpoint. These include such measures as: central beam alignment, unsharpness; contrast, basic spatial resolution, geometric distortions, laser beam function, blooming or flare, shading, erasure, and signal-to-noise ratio (SNR).

2. Imaging plate performance

2.1 Scatter characteristics

In a typical X-ray imaging system, an exposure consists of a combination of primary and scattered beams. CR systems' inherently greater sensitivity to low energy and low dose (Figure 1) make them even more susceptible to scatter; so it is of interest to characterize the proportion of primary beam to scattered beam, and determine ways to reduce scatter. In some cases, the scatter can be reduced with the use of lead-intensifying screens in front of the imaging media, in combination with appropriate collimation at the tube. Unlike conventional film systems, the response of CR imaging plates is not appreciably intensified with the use of lead screens. The absorption of the lead, rather than intensification, is key to managing the effects of scatter in a CR system.

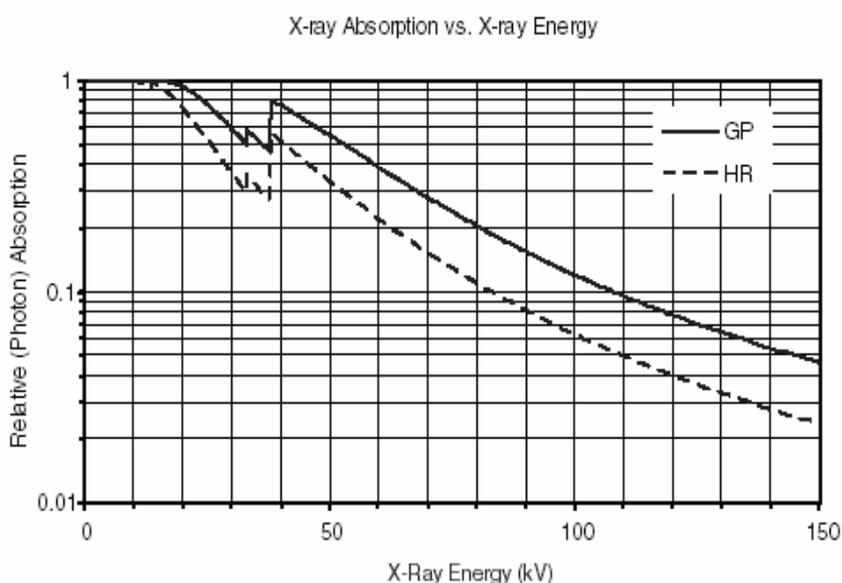


Figure 1. Absorption characteristics of phosphor imaging plates

2.1.1 Primary Scatter

The degree of primary scatter can be determined with a simple experimental setup. A thick, lead block is used to block half the beam at the tube and, in the “shadow” of this block, a thin step wedge consisting of stacked pieces of 0.125 mm (0.005in.) lead-intensifying screens is placed on the IP. Also thick, lead blocks are placed on the margins of the IP for an attenuation reference. A lead plate is placed behind the IP to eliminate backscatter. An exposure is made at high potential, ie, 400 kVp or maximum tube output, and the resultant pixel values are recorded for each area of the IP. Then a lead collimator is placed between the tube and the lead block that is used to obscure half the beam, and the exposure and readout are repeated. The experimental setup is shown in Figure 2.

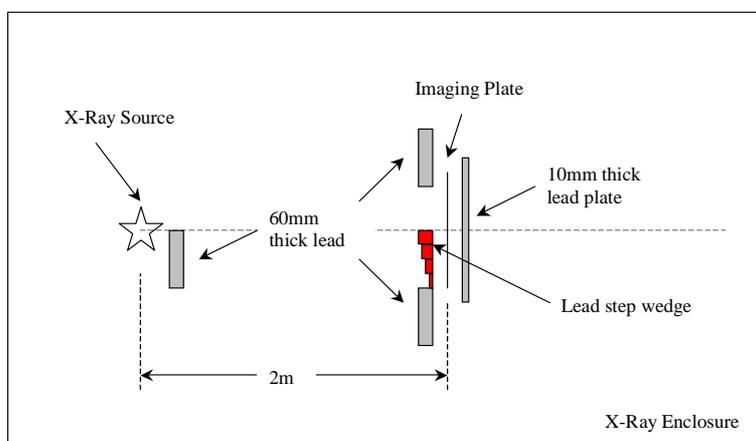


Figure 2. Experimental setup for the determination of primary scatter

A comparison of the gray values read from the various portions of the IP will reveal much about scatter. The difference between the scattered-beam area and the unattenuated area indicates the proportion of scattered-to-primary beam. The difference between the lead-screen step-wedge area and the scattered area indicates how effective the screens are in controlling scatter. Comparing results before and after collimation will give a clear picture of just what combination of collimation and lead screens are most effective in controlling primary scatter.

2.1.2 Backscatter

Examination of backscatter characteristics requires an exposure setup that totally blocks any exposure from the primary beam. This is accomplished by placing a thick, lead sheet or blocks over the IP. To verify this, there must initially be no backscatter, so a similar lead sheet or block is also placed behind the IP. A high X-ray potential is selected, i.e., 400 kVp or maximum tube output, with a 0.5 mm lead filter in front of the tube. Once the setup is verified to be X-ray tight, the lead behind the IP is replaced with a lead step wedge consisting of layers of 0.125 mm (0.005 in.) lead screens. Again, lead blocks in the outside

margins will provide an attenuated area for reference. This experimental setup is shown in Figure 3.

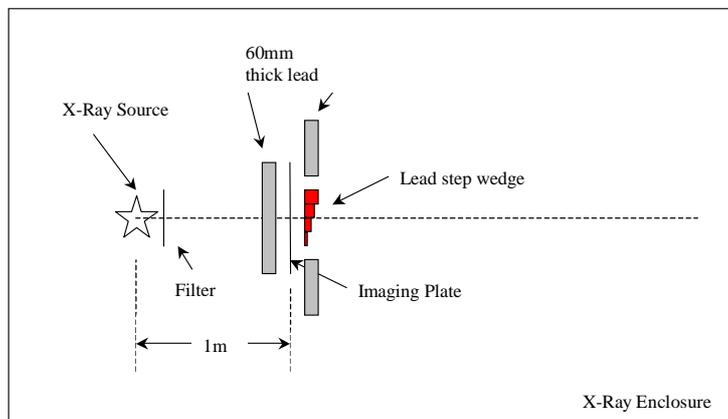


Figure 3. Experimental setup for the determination of backscatter

After an exposure is made, the resulting gray values are examined in the attenuated area and each step of the wedge. The thickness of the lead to optimally control backscatter is the thickness of the step in which its gray value approaches the gray value of the attenuated area. This procedure can be repeated for other X-ray potentials, but to be practical, it needs to be done only at the maximum anticipated working potential. In most cases, the thickness of the lead required to effectively control scatter in a CR system will be greater than that required for a conventional film system.

3. CR system measures

Having established a good understand of the effects of scatter and how to manage them, it is then possible to establish an optimum exposure setup and take a look at the measures of interest that relate more to the CR reader hardware. Unlike the physics of exposure, the hardware side of the CR system equation is more subject to degradation and deterioration, so there are a number of tools and measures that can be used both to establish an initial performance baseline and to monitor the performance and stability of the system over the long term. These tools are the basis of a new industry standard that was published late in 2005 as ASTM E 2445, "*Standard Practice for the Qualification and Long-term Stability of Computed Radiology Systems,*" ASTM International. Following is a brief description of each of these tools and measures.

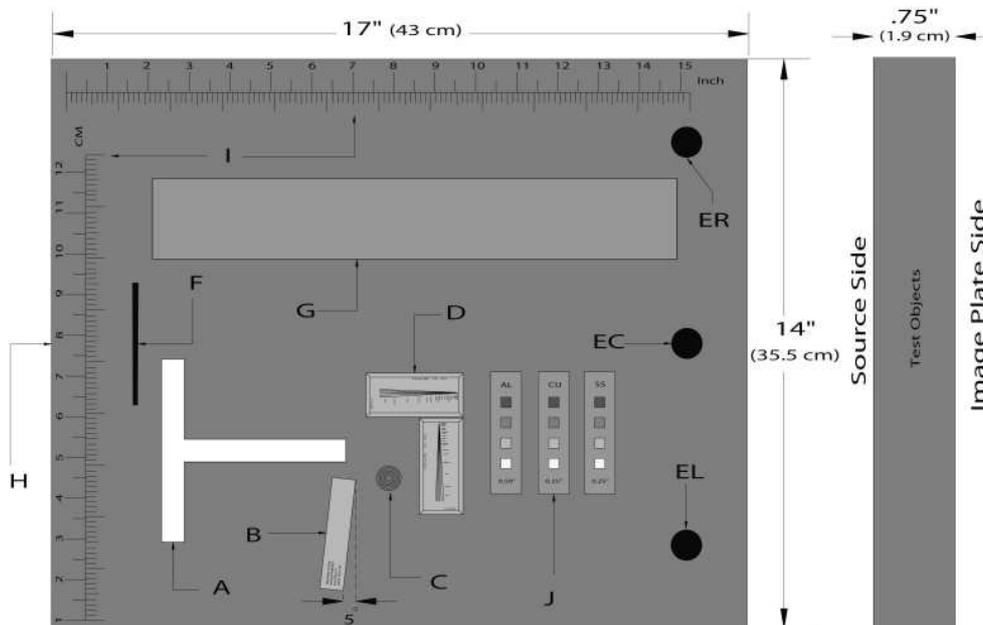


Figure 4. CR Phantom containing CR quality indicators for qualification of computed radiography systems.

The CR phantom in Figure 4 provides the tools to make the measurements we discuss below, including:

- A. T-target for blooming or flare detection
- B. Duplex-wire image-quality indicator
- C. Central beam alignment
- D. Converging line-pair quality indicators
- E. EL, EC, and ER measuring points for shading correction
- F. Cassette positioning locator (does not appear on the radiographic image)
- G. Homogeneous strip
- H. Lucite plate
- I. In./cm ruler for linearity check
- J. Contrast sensitivity quality indicators:
 - Aluminum: 12.7 mm (0.50 in.)
 - Copper: 6.35 mm (0.25 in.)
 - Stainless steel: 6.35 mm (0.25 in.)

3.1 Contrast sensitivity

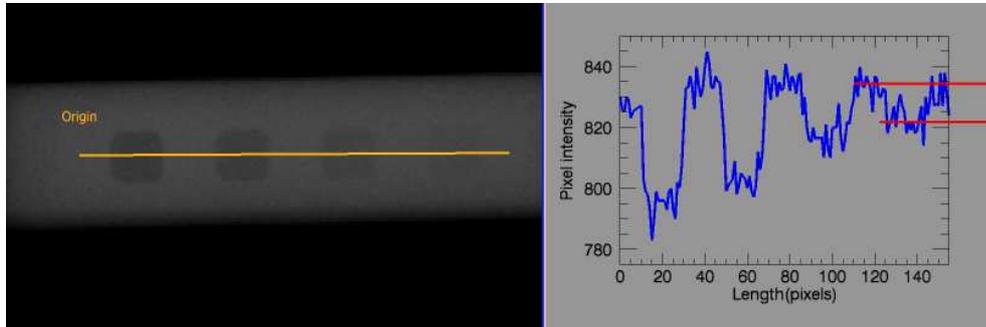


Figure 5. An image made employing the phantom's contrast sensitivity target

The contrast sensitivity of a CR system can be measured independently of the imaging system's spatial resolution limitations. The contrast sensitivity target corresponds to ASTM E 1647 and consists of three targets made from aluminum, copper, and stainless steel. Each target contains a contrast area for 1, 2, 3, and 4% wall-thickness contrast sensitivity. Evaluation can be either visual- or computer-aided, whereby a line profile is taken through the image of the target, and the average noise of the profile shall be less than or equal to the difference in intensity between the full and reduced wall thickness at the read-out percentage.

3.2 Unsharpness and basic spatial resolution

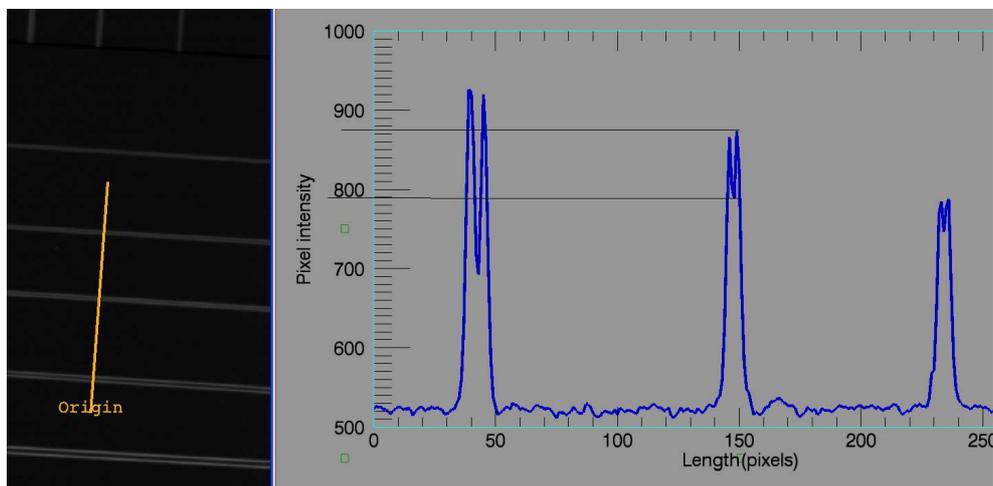


Figure 6. In this example: 12th pair = .13 mm unsharpness, .063 mm BSR

The spatial resolution of a CR system can be measured independently of the system's contrast sensitivity. For this measurement, the duplex-wire gauge corresponding to ASTM 2002 (or EN 462-5) is used. The target is positioned on the cassette with the IP and a lead screen in an orientation of 5° from perpendicular and parallel to the scanning

direction of the laser beam. This requires two exposures or one exposure with two gauges.

Because the measurement of unsharpness may depend on the radiation quality, exposures are made at 220 kVp for high-energy applications and/or 90 kVp for low-energy applications. The first unresolved wire pair is taken for determination of the unsharpness value. This is the first wire pair with a dip between the two wires of less than 20% of the maximum intensity (see Figure 7). The system resolution is taken as one-half the unsharpness.

Given that the resolution increments of the E 2002 duplex wire gauge are in finite steps, the determination of basic spatial resolution, according to the Standard, may not allow a detailed enough view for discerning users to notice and take timely action on small or very gradual degrees of performance degradation. Such users have a couple of additional options. One approach is to monitor the percent dip of the smallest resolved wire pair, which will be in the range of 25– 35%, for example. Another approach is to interpolate between the last resolved pair and the first unresolved pair, and calculate the basic spatial resolution corresponding to a dip of 20%. Both of these methods will yield a more accurate determination of resolution, and allow the user to take earlier corrective action for system degradation, if desired.

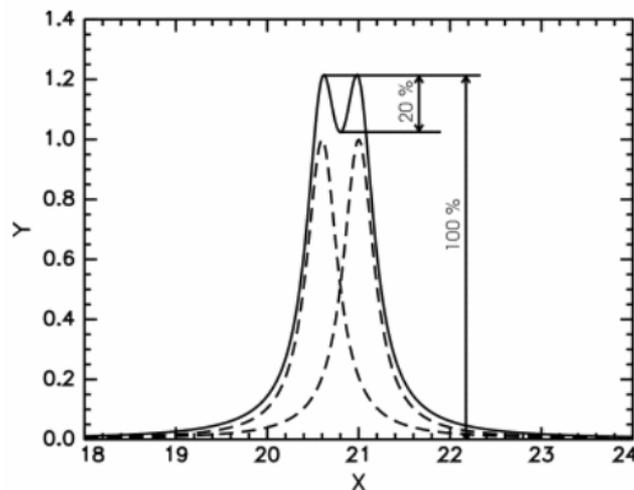


Figure 7. Line profile of duplex wire pair showing at least 20% dip in intensity between the two wires

Also, resolution in line pairs/mm is measured using converging line-pair gauges. These gauges are placed on the cassette in orientations perpendicular and parallel to the scanning direction of the laser beam.

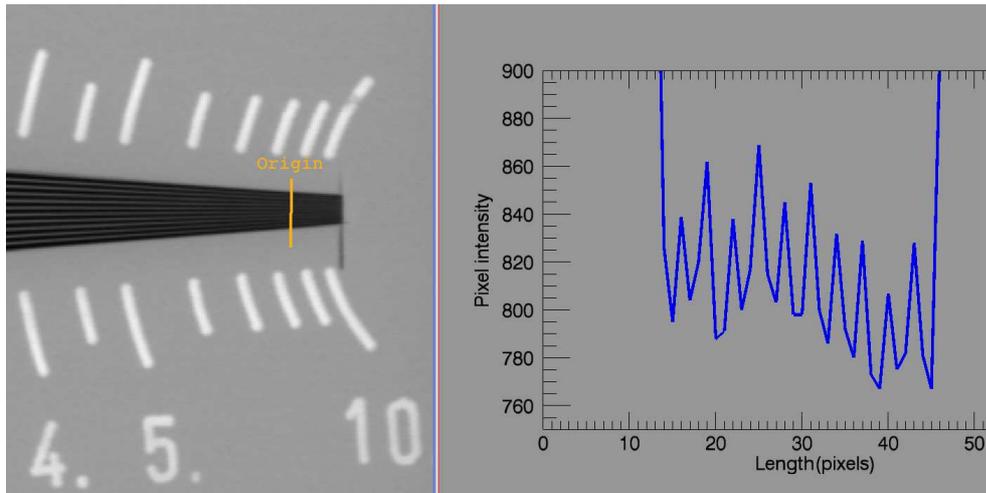


Figure 8. An example of converging line-pair evaluation, showing a computer-aided analysis at 8.5 line pairs/mm.

Although the contrast sensitivity and resolution are measured independently, overall CR system performance can be specified as the combination of the measured contrast sensitivity (expressed as a percentage) and the spatial resolution (expressed in mm of unsharpness). For example, a CR system that exhibits 2% contrast sensitivity and images the 0.1 mm wire pair performs at a 2% – a 0.2 mm sensitivity level.

3.3 Geometric distortions



Figure 9. Example of a measurement at one end of the IP using the phantom's metric ruler

Spatial nonlinearities are checked using spatial linearity quality indicators (rulers) oriented both perpendicular and parallel to the direction of the laser beam scan. Measurements are taken along the ruler, across the width and length of the IP, and these measurements should be consistent within 5% of each other across each dimension of the plate.

3.4 Scanner slipping

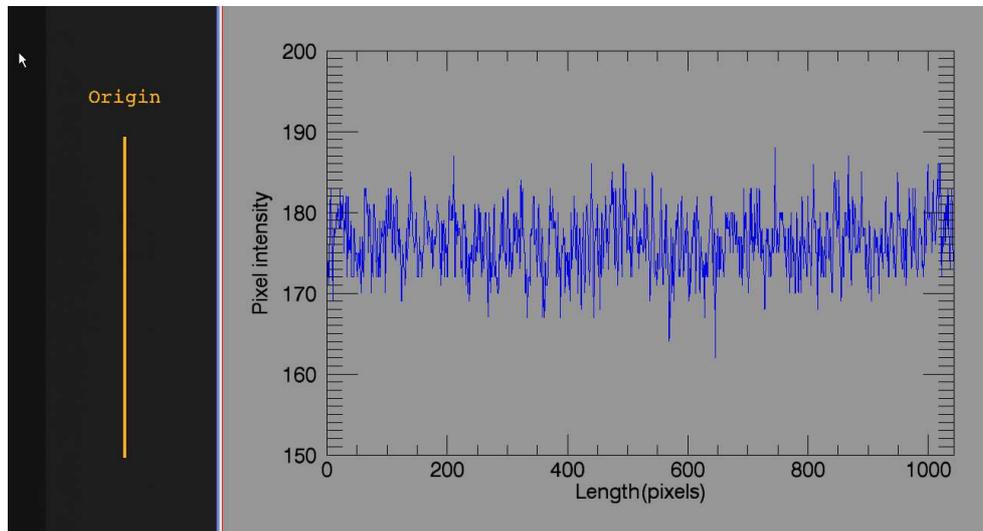


Figure 10. This example shows a smooth and uniform transport of the IP, measured with a density profile tool. A smoothed curve should not vary more than the “system noise” at any point.

A homogeneously exposed area is used to check for any slipping of the IPs in the scanner, as such slipping would result in deviations in the intensity of the scanned lines. Any deviation in intensity greater than the system noise is an indication that the IPs are slipping or that there are other distortions in the homogeneity of the scanning and reading system.

3.5 Blooming or flare

A “T-Target” provides areas with high-density contrast in both directions. These high-contrast edges are examined for evidence of intensity overshoot or streaking, which can be caused by saturation of the light detector. This would appear as intensity transfers from regions with high light intensities into dark regions with low intensity and can be evaluated easily using a density profile.

3.6 Shading

This test is used to ensure that the scanning laser intensity is uniform across the scanning width of the IP, as well as to check for proper alignment of the light-guide/photo-multiplier tube assembly. The IP is exposed homogeneously to a source from a large distance (1 m to 5 m), and the resulting pixel values are measured at the center and edges of the IP. The outside areas should not have a pixel intensity value exceeding $\pm 10\text{--}15\%$ of the central area of the IP for exposures made at a distance of 5 m and 1 m, respectively.

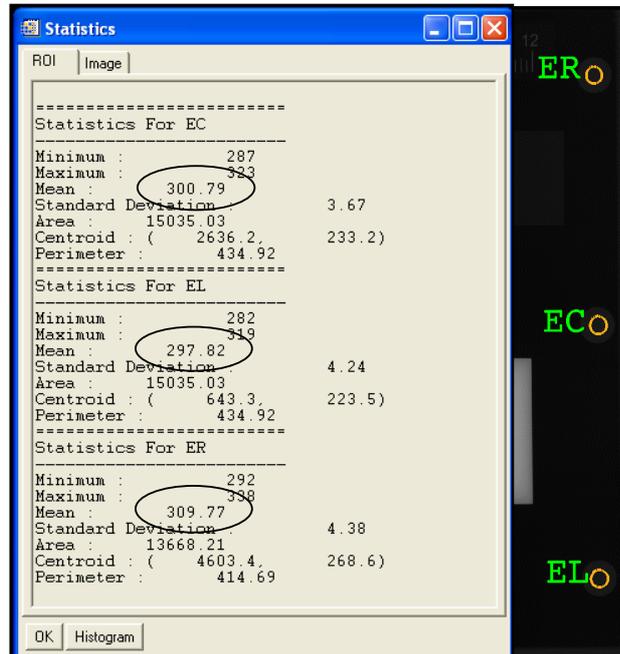


Figure 11. This shows three regions of interest (ROIs) on the right (ER), center (EC), and left (EL) edges, which are examined for mean pixel response. Total shading should not exceed $\pm 15\%$, which includes 8% inherent shading with an SDD of 39 in.

3.7 Erasure

Proper erasure of an IP ensures clean, ghost-free images for each exposure/read cycle. To test for proper erasure, an object of high absorption (eg, tungsten or lead) is exposed on the IP, resulting in an image of both the object and an unattenuated area. After the IP is read and erased in the normal manner, it is processed through the CR reader again without any additional exposure. If any latent image exists, the erasure time is insufficient, or the eraser is malfunctioning. Possible ghost images should have an intensity of less than 1% of the maximum intensity.

3.8 Measurement of the normalized SNR

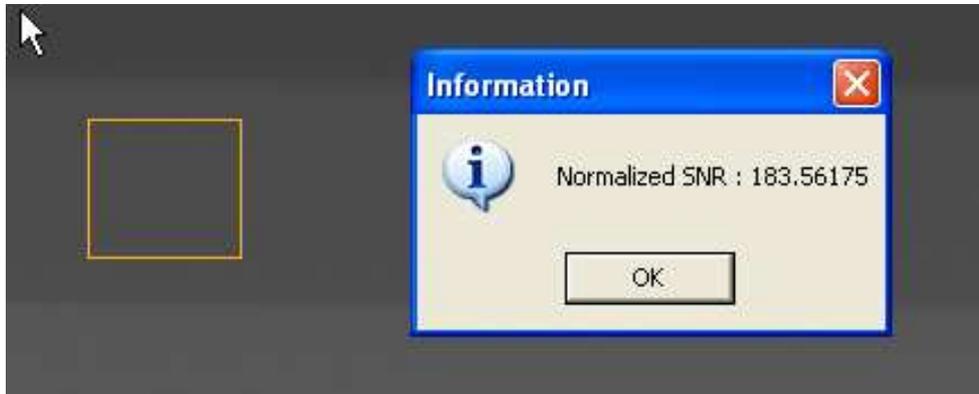


Figure 12. Modern software tools make short work of an otherwise complex calculation.

“Noise” in any electronic or digital system is any undesired signal(s) interfering with normal detection or processing of a desired signal. Simply put, it degrades the performance of the system, so it is important to characterize the ratio of desired signal to undesired signal, or SNR. This measurement is typically accomplished through the use of software tools, such as the one embedded in Kodak Industrex digital viewing software, that examine the mean and standard deviation of pixel values in a uniformly exposed field. The algorithm normalizes this value by taking into account the measured basic spatial resolution, as well as the shape (square vs. round), of the pixels.

The normalized SNR parameter is quite telling of the capability of a CR system, and is, in fact, the basis of the standard, ASTM E 2446, “Standard Practice for Classification of Computed Radiology Systems,” ASTM International, published in late 2005.

4. Summary

This paper has explored some basic methodologies for understanding the radiographic performance of a CR system, both in terms of the basic response of the IPs and the performance of the end-to-end CR system. Of course, there are many other possible measures, such as modulation transfer function (MTF) and detector quantum efficiency (DQE). However, many of these other measures are beyond what a typical user is willing or able to do routinely. The tools and measures presented herein will serve most users well and will ensure that a CR system is operating at its optimum capability.

Acknowledgements

Adapted from an article that appeared in the March 2006 issue of ASNT Materials Evaluation.

References

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