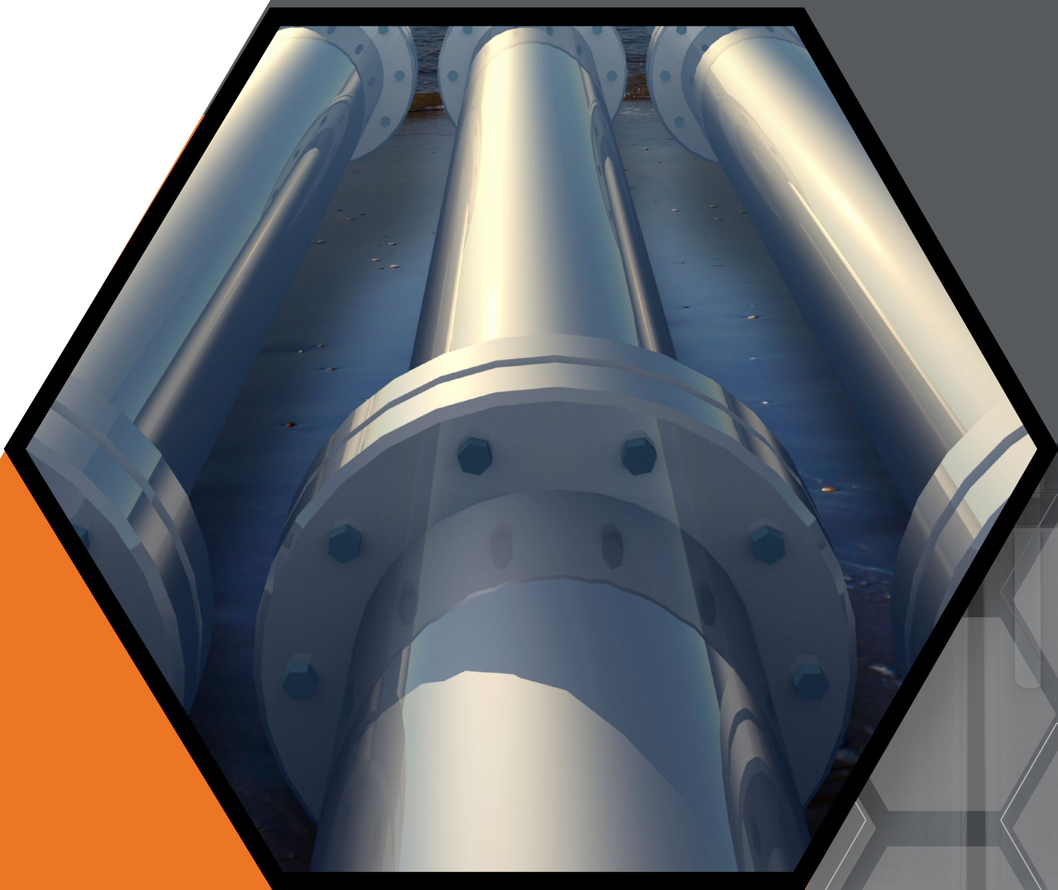
CarestreamNDT

WHITE PAPER

Exploring the effect of scintillator choice on Digital Detector Array Image Quality

Best practices on DDA construction that contribute to achieving the best quality image possible.



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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Digital detector arrays (DDAs) are becoming more prevalent in industrial digital radiography (DR) inspection processes. Although several factors in radiographic technique such as dose level or scatter control measures have a profound impact on the radiographic process results, the type of scintillator used with a DDA determines the overall achievable image quality. In order to guide our selection for the best scintillator options, we investigated DRZ High, DRZ Plus, DRZ Standard, and DRZ Fine gadolinium oxysulfide terbium (GOS: Tb) activated scintillators with the Carestream HPX-DR digital detector array panel. Three X-ray beam conditions were utilized for exposure: RQA-5 (70 kVp, 21 mm aluminum), RQA-9 (120 kVp, 1 mm copper and 4 mm aluminum), and NDT (220 kVp, 8 mm copper). DR image quality-related parameters such as detective quantum efficiency (DQE), modulation transfer function (MTF), sensitivity, and interpolated basic spatial resolution (iSRb) were determined for each scintillator and beam condition.

Before anything, what is a scintillator?

ASTM E1316 Standard Terminology for Nondestructive Examinations defines scintillators as "a detector that converts ionizing radiation to light." Those detectors have direct use not only in the manufacturing of DDAs for digital radiography devices but also in radiology applications where real-time images are produced. Amorphous silicon detector arrays by themselves do not react to X-rays. Amorphous silicon is only sensitive to visible light. Therefore, the need for a scintillator that converts X-rays to visible light that the array can actually detect is relevant, and hence the importance of choosing the proper scintillator for your intended application. Once a choice of scintillator is made, it can't be substituted by a different one because it is permanently built into the DDA. Scintillators utilized for DDAs have phosphors that are prompt emitting, meaning that when X-ray or gamma rays expose the scintillator, it immediately glows with visible light.

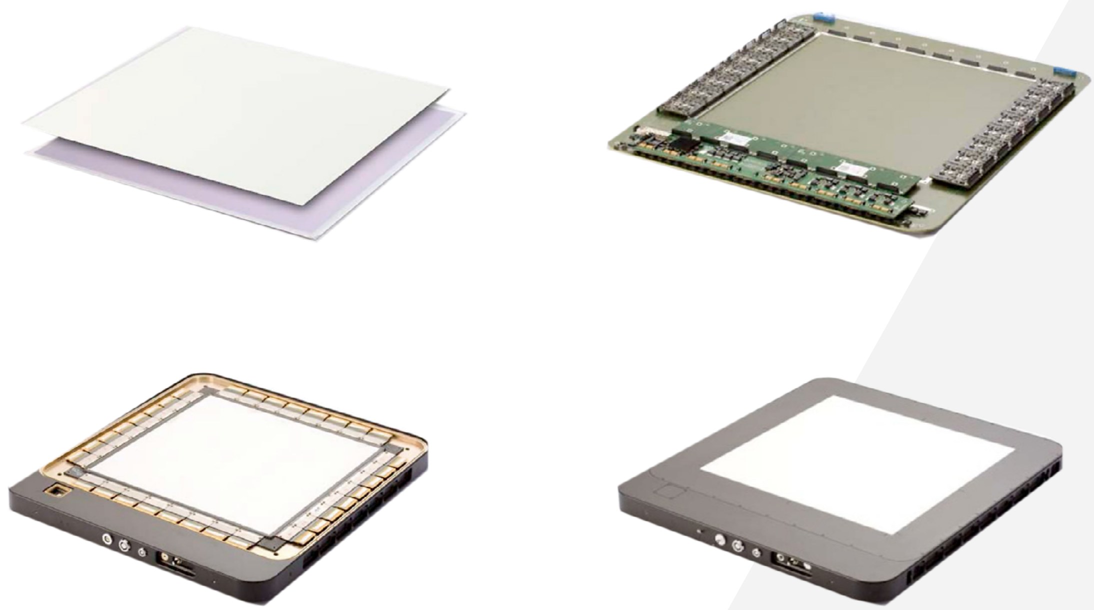
ASNT's Nondestructive Testing Handbook, fourth edition: Volume 3, Radiographic Testing expands the fundamental definition above with guidelines related with their desirable properties in the following terms: "Scintillators are materials that convert X-rays, gamma ray photons, or neutrons into visible-light photons, which are then converted to a digital signal using technologies such as amorphous silicon arrays, CCDs, or CMOS devices together with an analog-to-digital converter. Since there are various stages of conversion involved in recording the digital image, it is very important to ensure that minimal information is lost during conversion in the scintillator. The desired properties for ideal scintillators include the following: 1) High stopping power (high absorption and attenuation) for the desired radiation. A high percentage of heavy elements is typically required to achieve this for X-rays and gamma rays, 2) High X-ray to light conversion efficiency light yield), 3) Matched emission spectrum of the scintillator to the spectral sensitivity of the light collection device, 4) Low afterglow and burn-in to avoid lag and ghosting in subsequent images or scenes, 5) Stable, linear performance with X-ray dose, 6) Temperature independence from light output, and 7) Stable mechanical and chemical properties." Ghosting or detector image lag refers to the latent image that remains on the DDA for the current exposure derived from a previous exposure.

DDA's construction and image quality principles 101

DDA technology has increasing acceptance within the NDE industry due to a series of workflow advantages (see the Digital Radiography 101 section, including Table 1, of our white paper "In the path of digital transformation, Dose is still King"). In parallel, nearly all medical radiological applications have converted to indirect DDAs.

DDAs are electronic imaging devices that convert X-rays or gamma rays to light, which is stored as a voltage and is subsequently sampled to form the digital image (see upper left top in the first image in Figure 1(a)). There are two common types of scintillators for radiology and radiography: cesium iodide thallium (CsI:Tl) and gadolinium oxysulfide terbium (GOS: Tb). CsI-type scintillators are not commonly used for industrial radiography because of ghosting issues above 150 kV; therefore, GOS-type scintillators are almost always chosen for NDT applications.

GOS-type scintillators are optically coupled to a piece of glass that contains a patterned array of pixels. Each pixel contains a photodiode, which senses the light from the scintillator, and a thin film transistor (TFT), which stores the charge created by the photodiode. The thickness and phosphor size of the scintillator has a profound influence on the overall quality of the digital image, which is a combination of brightness, sharpness, and noise. Although this is an important influence, scintillator type is often overlooked, as it determines whether or not the DDA can meet inspection requirements.



(a) The sequence of Construction of a DDA.

(b) Physical configuration of Carestream's HPX-DR DDA and mount kit.

Figure 1 – Examples of physical constituents used in the manufacturing of DDAs, based on White, B., Shafer, M., Russel, W., Fallet, E., Roussilhe, J., & Toepfer, K. [9].

Detective quantum efficiency (DQE) provides a quantitative way to measure the detection capability of an imaging system for given exposure parameters and is a measure of image quality as a function of spatial frequency. Spatial frequency is a characteristic of any structure that is periodic across positions in space. The spatial frequency is a measure of how often sinusoidal components of the structure repeat per unit of distance (as determined by the Fourier transform). The SI unit of spatial frequency is cycles per meter (m). In image-processing applications, spatial frequency is often expressed in units of cycles per millimeter (mm) or equivalently line pairs per mm.

Mathematically, DQE is defined by the following equation (if you perceive it as challenging, please review our note on the inclusion of mathematical equations in articles describing practical applications in our white paper "Imaging Plate Use for Radiographic Nondestructive Evaluation - Best practices directed to achieve the best quality image possible derived from our hands-on practical experience"

$$DQE(f) = \frac{q \cdot g^2 \cdot T^2(f)}{NNPS(f)}$$

In this equation:

- DQE(f) denotes that the detective quantum efficiency is a function of spatial frequency,
- q is the density of incident quanta per unit area at the detector (flux),
- g is the system gain, that is related with the amplification of the received signal
- T is the MTF[1], and
- NNPS is the normalized noise power spectrum.

[1]MTF is a way to measure the achievable detail that a system can obtain. The MTF describes the contrast of an image as a function of spatial frequency. MTF is calculated by measuring the edge response of a tungsten phantom with a very sharp angle. A line profile is drawn in the radiograph across the sharp angle, resulting in an edge spread function (ESF). Taking the derivative of the ESF results in a rate of change across the angled edge, which is known as the line spread function (LSF). An oversampled LSF has a Fourier transform applied to it to yield the contrast modulation as a function of spatial frequency, as the Fourier transform decomposes the LSF into the frequency domain.

Basic spatial resolution (SRb) is a measure of the amount of detail that can be seen in an image with a duplex wire gauge placed directly on the detector. The duplex wire gauge consists of several elements. Each element has two wires with a specific diameter and spacing between them. In an image, a line profile is drawn perpendicular to the elements. The element is said to be resolved if the intensity difference is greater than 20% of the wires against their background.

Description of the experiment and results obtained

Four different GOS-type scintillators were investigated in combination with the Carestream HPX-DR DDA (see Figure 1(b)). Three different X-ray beam conditions and four different scintillators were used. Table 1 presents GOS scintillator types.

Scintillator Type	Supporting Layer (µm)	Phosphor Layer (µm)	Protective Layer (µm)	Total Thickness (µm)
DRZ High Resolution	250	70	6	326
DRZ Fine	250	110	6	366
DRZ Standard	250	140	6	396
DRZ Plus	250	210	6	466
DRZ High	170	310	9	489
DRZ PI200	170	420	6	596

Table 1: DRZ scintillator types.

The experiment aimed to explore a palette of several practical usages. The DRZ Fine, Standard, Plus, and High were investigated. The DRZ Plus screen is chosen for DDAs that utilize GOS for low-resolution applications. The DRZ Standard screen is utilized for some NDT applications; however, the DRZ Fine screen has been introduced for DDAs with smaller pixel pitch. We wanted to determine, through scientific analysis, the best scintillator for our HPX-DR DDA panel, which has a pixel pitch of 139 µm.

The four GOS-type screens were placed in pressure contact with a TFT photodiode array. Exposures were performed with standardized beam conditions, RQA-5 and RQA-9 from IEC 62220-1. IEC is the International Electrotechnical Commission—which are used in medical radiology, and NDT, which is commonly used for industrial radiography. Individual images were acquired for the dark calibration, gain calibration, flat-field noise power spectrum, slanted-edge MTF target, and duplex wire gauge. The MATLAB software suite was utilized for the analysis of the DQE and MTF.

For the DQE comparisons, the exposure was adjusted to match the DRZ Plus signal level and the results obtained are described in the series of graphics that are included in Figure 2.

The overall image quality was measured by DQE analysis. Figures (a), (b), and (c) of Figure 2 present the DQE results for the four GOS screens at the three beam conditions. The DRZ Standard scintillator had the best DQE above 2 cycles/mm. Below 2 cycles/mm, the DRZ Plus scintillator was the best choice as the DRZ High lacked sufficient sharpness for consideration. The DRZ Fine screen did not have suitable image quality except at very high spatial frequencies. As the kV increased, the overall achievable image quality decreased.

Scintillator Type	Analog-to-digital converted unit per exposure (ADu per mR)	
	RQA-5	RQA-9
DRZ Fine	2224	2607
DRZ Standard	3503	4132
DRZ Plus	4445	5477
DRZ High	6229	7871

Table 2: DRZ scintillator sensitivity., from White et al [9].

Figures (a), (b), and (c) of Figure 3 present the MTF results for four different screens at the three beam conditions. The sharpness of the DRZ Fine scintillator was clearly the best across all spatial frequencies, followed by the DRZ Standard, DRZ Plus, and the DRZ High. The sharpness decreased at higher kV for all GOS screens.

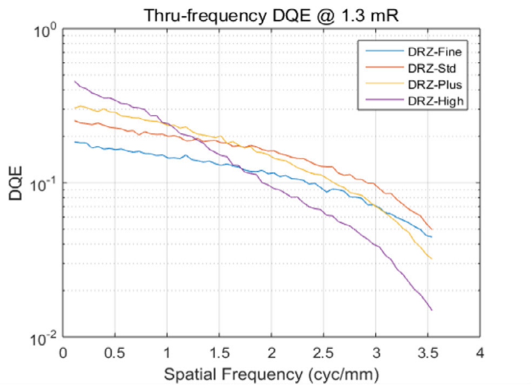
Scintillator Type	Resolution (μm)		
	RQA-5	RQA-9	220 kV, 8 mm Cu
DRZ Fine	95	100	105
DRZ Standard	120	125	130
DRZ Plus	160	160	160
DRZ High	225	225	225

Table 3: Duplex wire gauge resolution values, from White et al [9].

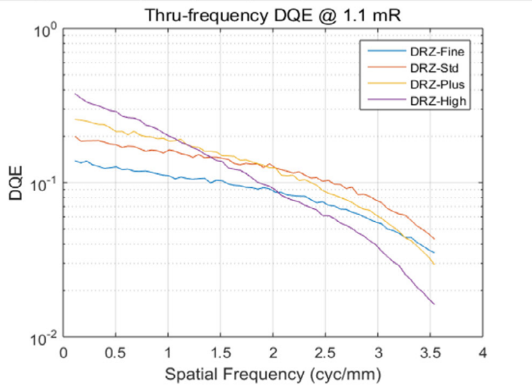
Table 3 presents the interpolated basic spatial resolution results for the duplex wire gauge method. The four scintillator screens were tested using the three beam conditions.

Resolution below the pixel pitch of the detector was achieved with the DRZ Fine screen. The DRZ Standard screen gave a resolution near or below the pixel pitch, whereas the DRZ Plus screen resulted in a resolution above the pixel pitch. The DRZ High screen had a resolution much higher than the pixel pitch of the detector. In general, the sharpness became worse as the kV was increased.

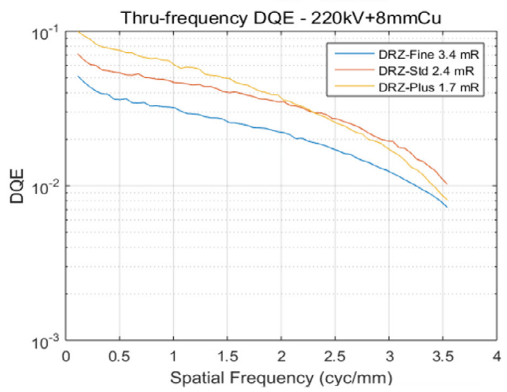
The DRZ Standard GOS scintillator screen was the best choice for NDT applications utilizing the Carestream HPX-DR digital detector array panel. The choice of the DRZ Standard screen resulted in the best overall image quality above 2 cycles/mm, and with images that had sharpness that was at or below the pixel pitch of the detector.



(a) DQE Comparison for RQA5, 70 kV, 21 mm Aluminum.

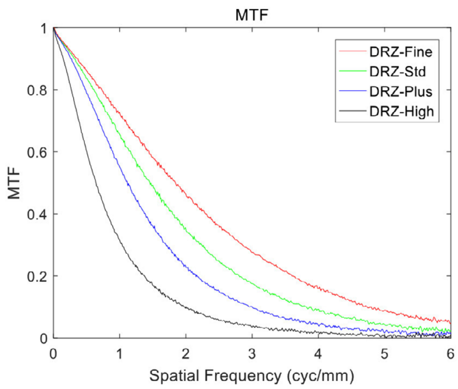


(b) DQE Comparison for RQA9, 120 kV, 1 mm Copper and 4 mm Aluminum.

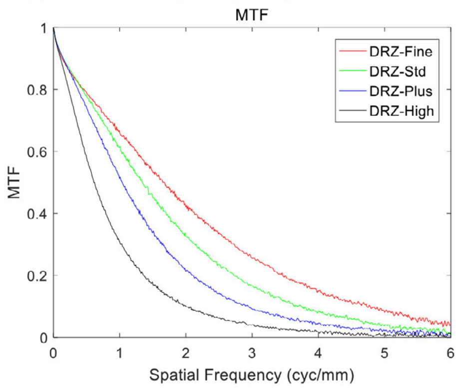


(c) DQE Comparison for 220 kV, 8 mm Copper.

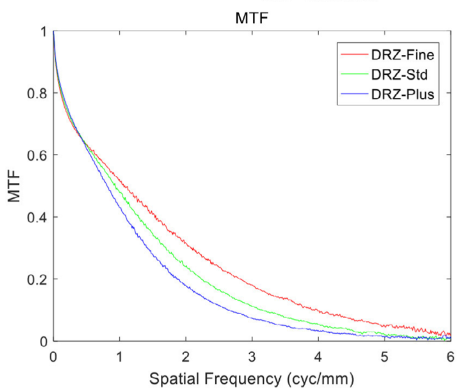
Figure 2 – Detective quantum efficiency (DQE) results for DRZ scintillaros, based on White, B., Shafer, M., Russel, W., Fallet, E.,



(a) MTF comparison for RQA5, 70 kV, 21 mm Aluminum.



(b) MTF comparison for RQA9, 120 kV, 1 mm Copper and 4 mm Aluminum.



(c) MTF Comparison for 220 kV, 8 mm Copper.

Figure 3 – Modulation transfer function (MTF) results for DRZ Scintillators, based on White, B., Shafer, M., Russel, W., Fallet, E.,

Where can I innovate in my everyday work? - Guidelines to select optimum scintillator type

Brian White, Research Scientist and Level III Radiographer at Carestream NDT, explains the practical implications of the results obtained from this series of experiments in the following terms [10]: "As the thickness and phosphor size of the GOS scintillator is changed, the brightness, sharpness, and noise of the image changes dramatically. Most radiographers do not realize that the scintillator choice determines the image quality of the DDA, and it is often overlooked and taken for granted. Thinner GOS scintillators with smaller phosphors will result in images that are sharper, with reduced brightness and improved noise uniformity.
Likewise, thicker GOS scintillators with larger phosphors will result in images that have reduced sharpness, with increased brightness and degraded noise uniformity. The balance of the sharpness and the signal-to-noise ratio will determine the overall image quality. Therefore, the proper choice of scintillator determines whether or not the DDA can meet inspection requirements. The brightness of the scintillator helps to determine the amplification or gain of the system. Brighter scintillators can result in improved image quality if all else is equal. Relative to the DRZ Plus, the DRZ Fine was 2.0 times less sensitive, the DRZ Standard was 1.27 times less sensitive, and the DRZ High was 1.40 times more sensitive for the RQA-5 beam condition. "

How can I make use of the information in this white paper

For readers interested in exploring how computed radiography (CR) can be integrated into your processes:

https://www.carestream.com/en/us/nondestructive-testing-ndt-solutions

For readers interested in exploring supplementary white papers on practical application and innovation on imaging processes:

https://www.carestream.com/en/us/nondestructive-testing-ndt-solutions

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

Products:

- HPX-DR 3543 PE Non-Glass, Large Format Detector
- HPX-DR 2530 PH High-Resolution, Compact Detector
- HPX-DR 2530 PC High-Speed, Compact Detector
- HPX-DR 4336 GH High-Resolution, Large Format Detector
- HPX-DR 2329 GK, High-Resolution, Compact Detector

- INDUSTREX Digital Viewing Software
- Advanced Industrial Radiographic Training Academy
- NDT Archive Solution
- Virtual NDT Showcase
- Resource Center

Services - Training and Supplementary Resources:

- Digital Detector Array 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

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