CarestreamNDT

WHITE PAPER

In the path of digital transformation, Dose is still King.

Moving forward in DR transition based in sound foundations.

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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From Digitization to Digital Transformation

The notion of digital transformation is everywhere. You continuously stumble upon it while surfing the web, zapping on the television and shuffling between radio stations or podcasts. A simple search of this concept on the internet provides nearly 50 million results and more that 110,000 academic articles; but nevertheless, in face-to-face conversations many experts will struggle to provide a clear definition of what digital transformation means and what comprises a digital transformation strategy.

Regardless, if you are already engaged in digital radiography (DR) processes, taking your first steps on the path of digital transformation of your imaging processes or are curious to start the journey through this route, this article aims to provide you with some valuable insights and practical tools to move forward on this path; but before all, it is important that we start from the beginning, which is reviewing if our terms are clear.

The NDE 4.0 Deployment Management Guidance Document **(see figure 1)**, which constitutes a cooperative effort between ASNT's NDE 4.0 Committee and the ICNDT Special Interest Group in NDE 4.0, provides the following series of definitions that will be useful for our understanding of both digital transformation and its implication of digital radiography deployment strategies:

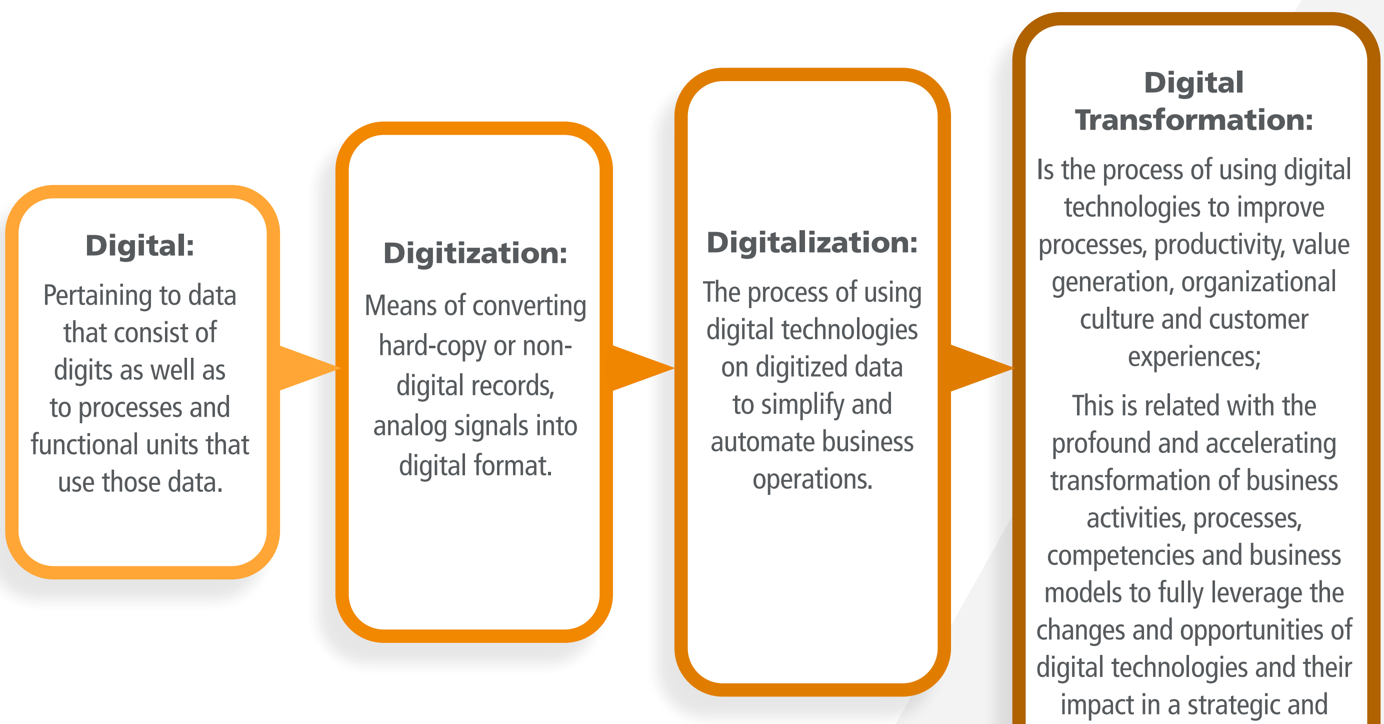


Figure 1: A series of definitions guiding the path to Digital Transformation, From the "NDE 4.0 Deployment Management – Guidance" document [1]

This series is relevant for our comprehension of digital technologies and their implications in digital transformation processes. Particularly, it is important to be aware of and clearly differentiate the notions of digitization and digitalization.

This same guidance document highlights the role that digital transformation processes are having in the non-destructive testing process for industry 4.0 in its own definition of NDE 4.0: *"Cyber-physical non-destructive evaluation (including testing); arising out of a confluence of industry 4.0 digital technologies, physical inspection methods, and business models; to enhance inspection performance, integrity engineering, and decision making for safety, sustainability, and quality assurance, as well as provide relevant data required to improve design, production and maintenance."*

Figure 2 presents the digital transformation cycle and the phases that comprise it. This three-phase cycle design allows the continuous improvement of digital transformation strategies moving from formulation, implementation and control through management processes. This third phase shall include Key Performance Indicators (KPIs) and metrics as well as a results assesment process in order to perfect both previous phases.

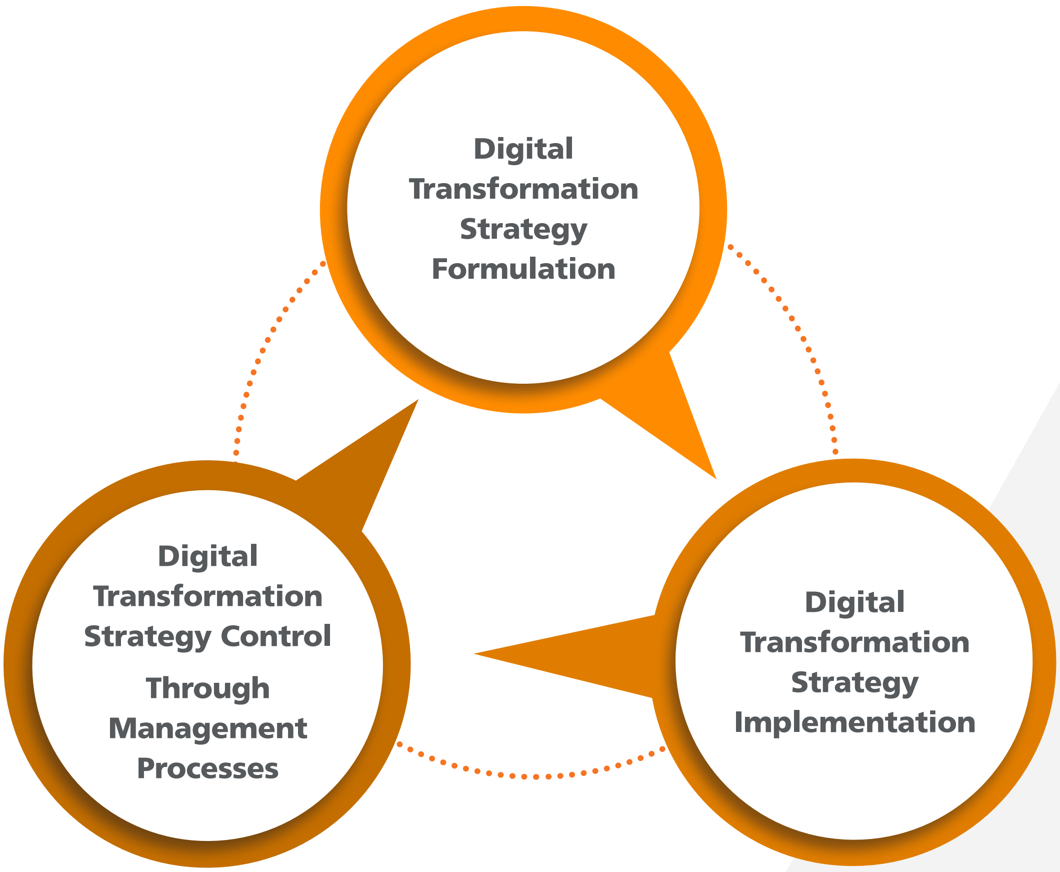
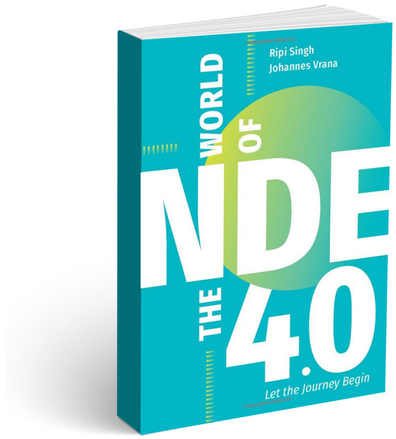


Figure 2: The digital transformation cycle, Adapted from Korachi and Bounabat [7]



Drs. Ripi Singh and Johannes Vrana in their Book "The World of NDE 4.0: Let the Journey Begin" reflect about the value of a profound understanding of the NDE ecosystem to guide the formulation, implementation and control of digital transformation strategies in the following terms: *"While each stakeholder sees economic value in digitization through efficiencies and effectiveness of systems, the real value of digital transformation comes when they are all a part of the same ecosystem where they breathe from the same data environment"*: they also consider the necessary synergy of the building blocks of NDE 4.0 solutions with those ecosystems: *"The key to such a digital transformation is the Industrial Internet of Things (IIoT) establishing open communication and digital twins as basis for enhanced data processing. The tools used by the stakeholders of the NDE ecosystem (like predictive maintenance or FEM) will become integral to the digital twins and will communicate using the same IIoT";* and finally, they highlight the importance of expert engagement for advancing digital transformation strategies: *"Digital transformation is at the heart of the fourth revolution and should be taken stepwise with expert engagement. It is not a 'Do it Yourself' (DIY) scenario yet. The number of technologies is plenty, and their integration creates so many opportunities that it can soon get overwhelming. Eventually digital transformation will lead to a situation where all the pieces of the great puzzle will come together to create a portrait of a better ecosystem and they all grow together."*

Digital Radiography 101

In order to visualize how to advance digital transformation strategies for Industrial Imaging process it is important to have a clear understanding of the fundamentals of the methods involved. Related with digital radiography, ASTM E1316 "Standard Terminology for Nondestructive Examinations" defines it as *"all radiography methods whereby images are in a digital format" and exemplifies it by identifying four separate sets of technologies: "For example CR (Computed Radiography), CT (Computed Tomography), DDA (digital detector array) and digitized film."*

Digital imaging, including digital radiography, is inexorably linked to technologies that allow the digitization of analog signals and also the advances and evolution of digital information systems and telecommunication technologies related to the storage, processing, retrieving, transmission, analysis and displaying of information. Today it is completely feasible through affordable computing devices to transport, store, and display digital radiography images that were technologically and economically challenging merely three decades ago.

Through this article we will focus our attention on DDAs, however many of the notions related to radiographic technique discussed here also are applicable to other sets of technologies that comprise digital radiography. ASTM E1316 defines a DDA as *"an electronic device that converts ionizing* *or penetrating radiation into a discrete array of analog signals which are subsequently digitized and transferred to a computer for display as a digital image corresponding to the radiologic energy pattern imparted upon the input region of the device."*

Brian White, Research Scientist and Level III Radiographer at Carestream NDT, explains the role of DDAs in digital radiography and highlights specific parameters that affect image quality in the following terms[2]: *"Digital detector array (DDA) systems are becoming more prevalent in the industrial radiography market. Exposure conditions largely determine the imaging results that are obtained for a given system. New guidelines will require the establishment of a pixel intensity range to achieve acceptable contrast sensitivity. The sensitivity will depend upon the radiographic technique, material type, material thickness, DDA type, integration time, and the number of averaged frames."*

Advantages of Digital Radiography Based in the Use of DDAs

According to ASNT's RT Handbook, *"Some of the same practices employed for film techniques can be applied to digital radiography with DDAs. The digital nature and speed of DDAs, however, offer some of the following benefits over film."* **Table 1** categorizes seven of their advantages:

Table 1. Advantages
1. Uses automation and manipulation to rapidly acquire imagery in succession using various part placements, angular views, magnifications, beam spectra, and imaging parameters.
2. Is amenable to in-line screening during manufacture or service
3. Has fully reusable media, with very short image time to view imagery, in many cases in real-time has ability to employ the same technology to perform CT and laminography.
4. Provides practical use of microfocus source and geometric magnification imaging for resolution rivaling or surpassing film.
5. Provides service across a very wide energy range, from 20 kev to 20 MeV.
6. Has quantitative and autonomous results/ detection and metrology analysis, with two-dimensional or three-dimensional digital radiographic imagery and is usable with other radiation sources directly, such as neutrons.
7. Can be used as wireless detectors for remote access without data cables connecting the detector to the computer.

Table 1: Advantages of DR processes, based in DDAs

Adapted from ASNT Nondestructive Testing Handbook, fourth edition: Volume 3, Radiographic Testing,[1]

Understanding Exposure Factors

As expressed in the first article of this series, obtaining adequate radiographic image quality is the result not only of the scientific principles that sustain the radiographic imaging process but also from the craft and experience that the radiographer put into function while defining an adequate radiographic technique.

ASNT Nondestructive Testing Handbook: Volume 3, Radiographic Testing 4th Edition expresses this amalgam of science principles, craft and experience in the following terms: *"Image quality, or sensitivity to detail, in radiography is described by the factors shown in **Figure 1**: contrast and resolution. Contrast is composed of the inherent subject contrast and the imaging system (detector) contrast. The inherent subject contrast is a function of the penetrating radiation type, energy selected, and its attenuation characteristic as a function of the thickness or material change in the subject. The overall contrast is also affected by the imaging system response curve to the penetrating radiation type and the dynamic range over which the detector can be operated. Scattered radiation at the detector will also reduce contrast by increasing noise. The resolution is composed of the inherent detector imaging system resolution of grain size for film/scintillators or pixel size for detectors, and the geometric magnification and unsharpness. Geometric magnification and unsharpness are affected by the source spot size, object size, and the relative source, object, and detector positions. The geometric setup of the X-ray exposure can influence contrast through the scatter radiation field. Orientation will also affect the ability to detect details."* That is, beside the traditional factors associated with film radiographic techniques such as source-to-object distance or geometric unsharpness, new factors such as integration time, contrast-to-noise ratio (CNR) or signal-to-noise ratio (SNR) shall be taken into account.

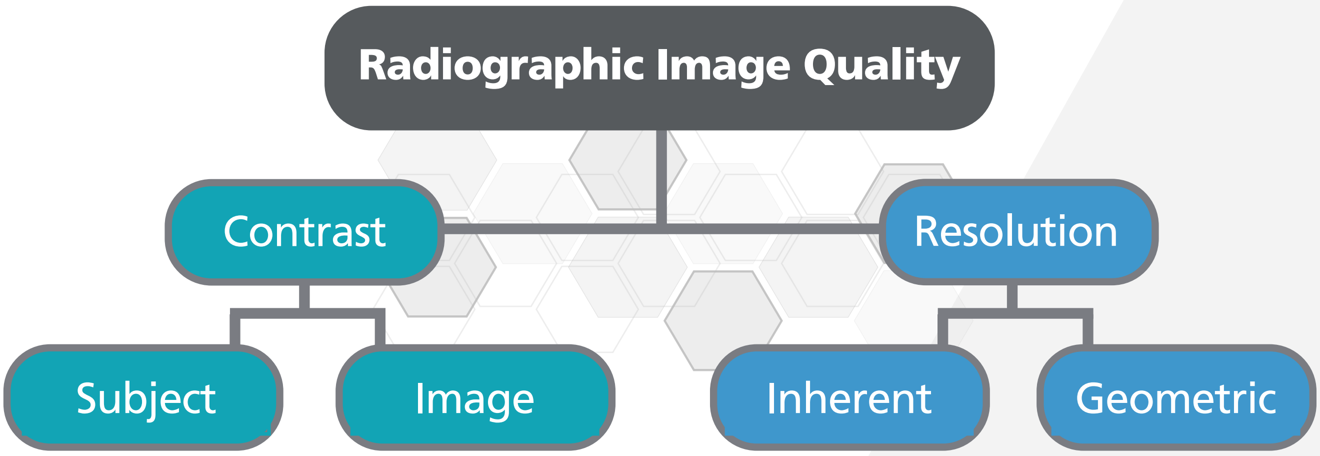


Figure 3: Factors that affect radiographic image quality,
from ASNT Nondestructive Testing Handbook: Volume 3, Radiographic Testing 4th Edition[1]

Exposure factor is an essential element of information that enables radiographers to decide important interrelated elements of the radiographic techniques and sequence. ASNT NDT Handbook explains its role and importance in the following terms: *"The exposure factor is a quantity that combines milliamperage (X-ray) or source strength (gamma rays), time, and distance. Radiographic techniques are sometimes given in terms of kilovoltages and exposure factor, or radioactive isotope and exposure factor,"* then it explains how it is related with the use of different radiation sources and provides an important notion—the reciprocity law: *"For an X-ray tube, changes in the filament current (mA) produce a direct change to the quantity of radiation emitted but have no effect in the radiation energy. Furthermore, filament current (mA) and time are usually interchangeable. Many X-ray techniques milliampere are defined by the milliampere second (mAa) or milliampere minutes (mAm) that are required at a given kilovoltage and distance to give the correct exposure. The production of milliamperage and time is constant for the same radiographic effect. This is known as the reciprocal law, and is valid for X-ray and gamma exposures over the range of radiation intensities and exposure used in normal industrial radiography. The operator may set the X-ray exposure based in the available current limitations of the x-ray tube at a particular kilovoltage setting. Reciprocity law failure can occur with film radiography at very high dose rates and/or very long exposures. Digital detector systems may also have restrictions on the length of integration time or intensity, based on their specific readout requirements."*

Therefore, the availability of accurate and useful information about the exposure factor is essential for any radiographer, regardless if they are using film or any digital radiography technique. That is why Carestream's research team, led by White, recently worked to provide exposure guidance for Carestream film and digital detector array products. **Table 2** compiles a list of the main parameters used to establish exposure factors for film and DDA radiography.

Table 2 - Experimental Parameters used to establish exposure factors for film and DDA Radiography
1. A masked steel step wedge with thickness of 0.25", 0.50", 0.75", 1.0", 1.25", 1.50", 1.75", 2.0" was used (See Figures 4 and 5)
2. Data collection SDD 12" for film & 24" for DDA
3. Iridium, Selenium, and Cobalt sources of gamma rays were used
4. Lead was used between wood table and detectors
5. Film tests used vinyl cassettes with front and back leads
6. DDA varied integration times, used 9 averaged frames
7. Utilized commercially available smartphone apps for the exposure calculations

Figure 4: Steel Step Wedge, from White[5]

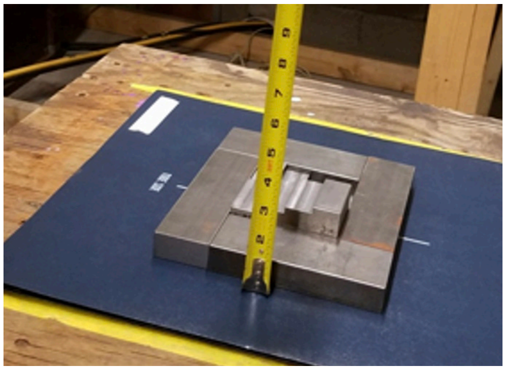


Figure 5: Radiographic Shot Configuration, from White[5]

The resulting exposure factors tables are:

Table 3							
Digital R Factor for HPX-DR 3543 PE							
	Pixel Intensity Desired						
Source Type	**3000**	**6000**	**9000**	**12000**	**15000**	**18000**	**21000**
Iridium	0.0112	0.0237	0.0366	0.0499	0.0635	0.0775	0.0918
Selenium	0.0011	0.0072	0.0113	0.0195	0.0258	0.0321	0.0384
Cobalt	0.0224	0.0529	0.0838	0.1151	0.1467	0.1787	0.2110
Digital R Factor for HPX-DR 2530 PC							
	Pixel Intensity Desired						
Source Type	**3000**	**6000**	**9000**	**12000**	**15000**	**18000**	**21000**
Iridium	0.0084	0.0205	0.0328	0.0452	0.0577	0.0702	0.0829
Selenium	0.0021	0.0082	0.0144	0.0207	0.0270	0.0334	0.0399
Cobalt	0.0161	0.0434	0.0708	0.0984	0.1263	0.1542	0.1824
Digital R Factor for HPX-DR 2530 PH*							
	Pixel Intensity Desired						
Source Type	**3000**	**6000**	**9000**	**12000**	**15000**	**18000**	**21000**
Iridium	0.0183	0.0423	0.0663	0.0904	0.1144	0.1385	0.1625
Selenium	0.0070	0.0190	0.0311	0.0431	0.0552	0.0673	0.0794
Cobalt	0.0586	0.1187	0.1788	0.2390	0.2993	0.3596	0.4199

***Note: The 2530 PH R factors can also be utilized for the HPX-DR 4336 GH (amplification gain setting of 4)**

Table 3: Factors that affect radiographic image quality,
from ASNT Nondestructive Testing Handbook: Volume 3, Radiographic Testing 4th Edition[1]

Exposure Factors in Practical Use

White provides in his presentation a practical example using a commercially available smartphone app devoted to exposure calculations. This app requires the following input parameters:

1. The activity measurement units should be selected between Curies or Tera-Becquerels (TBq)

2. The distance measurement units should be selected between inches or millimeters (mm)

3. Selection of Gamma source type should be made—here the app allows to choose between Iridium (Ir-192), Cobalt (Co-60) or Selenium (Se-75)

4. Input the following parameters:

a. Activity in the selected measurement unit

b. Steel thickness

c. The exposure "R" factor:

Typical R factors for film range from 1 up to 7, depending on film type and source type, CR is similar to film for R factors. Please note how the R factors for DDA's are significantly less as DDA's require significantly less exposure relative to film and CR, also note that these exposure factors are meant to provide guidance for a starting point to set integration time.

i. First you need to decide which DDA you will be using for performing the radiographic test.

ii. Once the DDA type is defined, you should establish the intended pixel intensity in the base metal portion of the image.

iii. Use Table 3 to select the proper "R" factor based in the selected DDA and which type of gamma ray sources will be used.

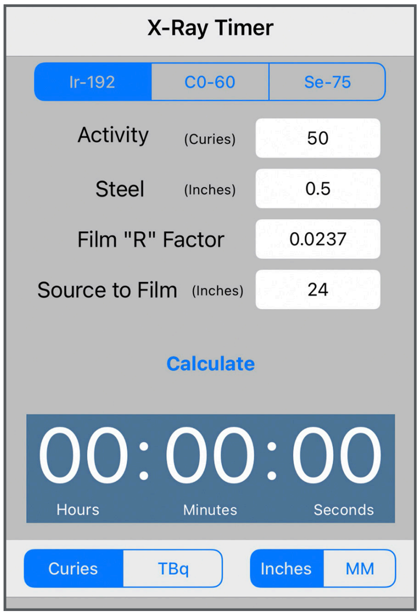
Press the word "Calculate" and the integration time will appear in the ***Hours:Minutes:Seconds*** field in the app.

Let's roll up our sleeves and put these notions in practice by solving an example provided by White in his presentation. The test parameters are as follows:

1. DDA type in use: HPX-DR 3543 PE polyimide 139 um pixel pitch
2. Gamma radiation source: Iridium
3. Source activity: 50 Curies
4. Steel thickness: 0.5"
5. Base metal target pixel intensity = 6000
6. Source to DDA distance (SDD) = 24"

Digital R Factor for HPX-DR 3543 PE							
	Pixel Intensity Desired						
Source Type	**3000**	**6000**	**9000**	**12000**	**15000**	**18000**	**21000**
Iridium	0.0112	0.0237	0.0366	0.0499	0.0635	0.0775	0.0918
Selenium	0.0011	0.0072	0.0113	0.0195	0.0258	0.0321	0.0384
Cobalt	0.0224	0.0529	0.0838	0.1151	0.1467	0.1787	0.2110

Based in a 6000 desired pixel intensity and the use of an Iridium source, the exposure or "R" factor is 0.0237 (see image above).



Capturing all the parameters above results in an integration time of two seconds.

If you want to practice this calculation process again with a different set of parameters, **Table 4** provides four supplementary examples that you can use:

Table 4				
Parameter:	**Example 1**	**Example 2**	**Example 3**	**Example 4**
DDA Type	**HPX-DR 3543 PE**	**HPX-DR 3543 PE**	**HPX-DR 2530 PC**	**HPX-DR 2530 PH**
Gamma Radiation Source	Cobalt	Selenium	Iridium	Iridium
Source Activity	25	25	50	50
Steel Thickness	2.5”	0.5”	1”	2”
Base Metal Target Pixel Intensity	6000	6000	6000	6000
SDD	32	24	24	20
Results				
“R” Factor	0.0529	0.0072	0.0205	0.0423
Integration Time	21 seconds	4 seconds	4 seconds	19 seconds

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

For readers interested in exploring how digital radiography (DR) can be integrated into 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:

<table>
<tr><th colspan="4">Products</th></tr>
<tr><th>Detector</th><th>Resolution and Size</th><th colspan="2">Characteristcs</th></tr>
<tr><td>HPX-DR 2329 GK</td><td>75 µm
230 x 290 mm</td><td colspan="2">Designed for industries that require ultra-high resolution for critical defect detection. Compact format for positioning in tight spaces.
Lightweight at 3.4 kg (7.9 lbs) with a slim 17 mm profile for ease-of-use in field imaging.
Designed and shielded for NDT applications.
Use less dose than film while still maintaining an optimal level of quality assurance to identify critical defects.
IP54 rated enclosure for industrial inspections,</td></tr>
<tr><td>HPX-DR 4336 GH</td><td>100 µm
350 x 426 mm</td><td colspan="2">100 micron image resolution for optimal image defect detection
Large format 43 x 36 detector allows for larger parts to be inspected in one shot
Lightweight (9.5 lbs./4.3 kg.) and slim profile (15.5 mm) for ease-of-use in field imaging
Designed and shielded for NDT applications</td></tr>
<tr><td>HPX-DR 2530 PH Non-Glass</td><td>98 µm
250 x 300 mm</td><td>Compact size and thin profile (14.7mm) for positioning in tight spaces
Robust industrial design without risk of glass breakage</td><td rowspan="3">Protective, weatherproof enclosure for use in harsh environments
Close-to-edge imaging maximizes surface area for image capture
Robust wireless connectivity for faster image transfer and analysis
Powerful lithium-ion batteries with battery 'hot-swap' to keep the detector running during battery change
Tungsten shielding for higher cumulative dose while preserving image quality</td></tr>
<tr><td>HPX-DR 3543 PE Non-Glass</td><td>139 µm
350 x 430 mm</td><td>Large format (350 x 430mm) and thin profile (14.7mm)
Robust industrial design without risk of glass breakage
Optional protective case and mount kit adds even more durability and product longevity</td></tr>
<tr><td>HPX-DR 2530 PC Non-Glass</td><td>145 µm
250 x 300 mm</td><td>Less required dose for shorter integration times and faster throughput
Compact size and thin profile (14.7mm) for positioning in tight spaces</td></tr>
</table>

Other products and services featured in this document:

Products:

- **INDUSTREX Digital Viewing Software**

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., (2020), Article "Exposure Guidance and the Myth of Pixel Value Dependence for Digital Detector Array Radiography" ASNT Annual Conference, Virtual, 2020.
4. White, B., Presentation "Exposure Guidance and the Myth of Pixel Value Dependence for Digital Detector Array Radiography" 20th World Conference, 2020.
5. White, B., (2020), Presentation "Exposure Factors for Film and Digital Detector Array Radiography" June of 2020.
6. ICNDT SGI, (2021), "NDE 4.0 Deployment Management Guidance" October of 2021.
7. Korachi, Z. & Bounabat, B. (2020). General Approach for Formulating a Digital Transformation Strategy. J. Comput. Sci, 16, 493-507
8. Singh, R., & Vrana, J. (2021). "The World of NDE 4.0: Let the Journey Begin". ISBN-13: 979-8462514210

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