CarestreamNDT

Digital Transformation

WHITE PAPER

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.

CarestreamNDT

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Looking forward based in the fundamentals of NDE

In the first NDE lessons, apprentices are taught the four indispensable elements of an NDE test system: ***1) An energy source, 2) A test object, 3) The interaction between that energy source and the test object and 4) A recording medium for this interaction.***

While analyzing how the test system does not function in the absence of one or more of those four elements, ineludibly a fifth presence, human intervention, is often overlooked for its explicit omnipresence which needs to assimilate and capitalize a rising sixth presence, artificial intelligence (AI). If properly assimilated, AI could be a source of extraordinary opportunities and an unmistakable ally to assist humans in unleashing the power of their talent and ingenuity to create and deploy the next generation of NDE systems in the following years.

NDE serves humankind by preserving life and property while generating data, information, and knowledge to support decision making processes. **Figure 1** shows a four-stage process of how NDE data is transformed into action through analysis and evaluation, e.g. radiographic inspection using digital detector arrays (DDA's). Trampus, Krstelj and Nardoni[5] remind us the fundamental objectives of NDE: *"In broad sense, NDT has two fundamental objectives. Its social objective is to save the human and the natural and built environment in case a structure or component fails due to non-detection of a flaw. A failed structure or component can often jeopardize its environment and human life. The commercial objective of NDT is to optimize the productivity of assets, i.e. components or structures of the entire facility being inspected".*

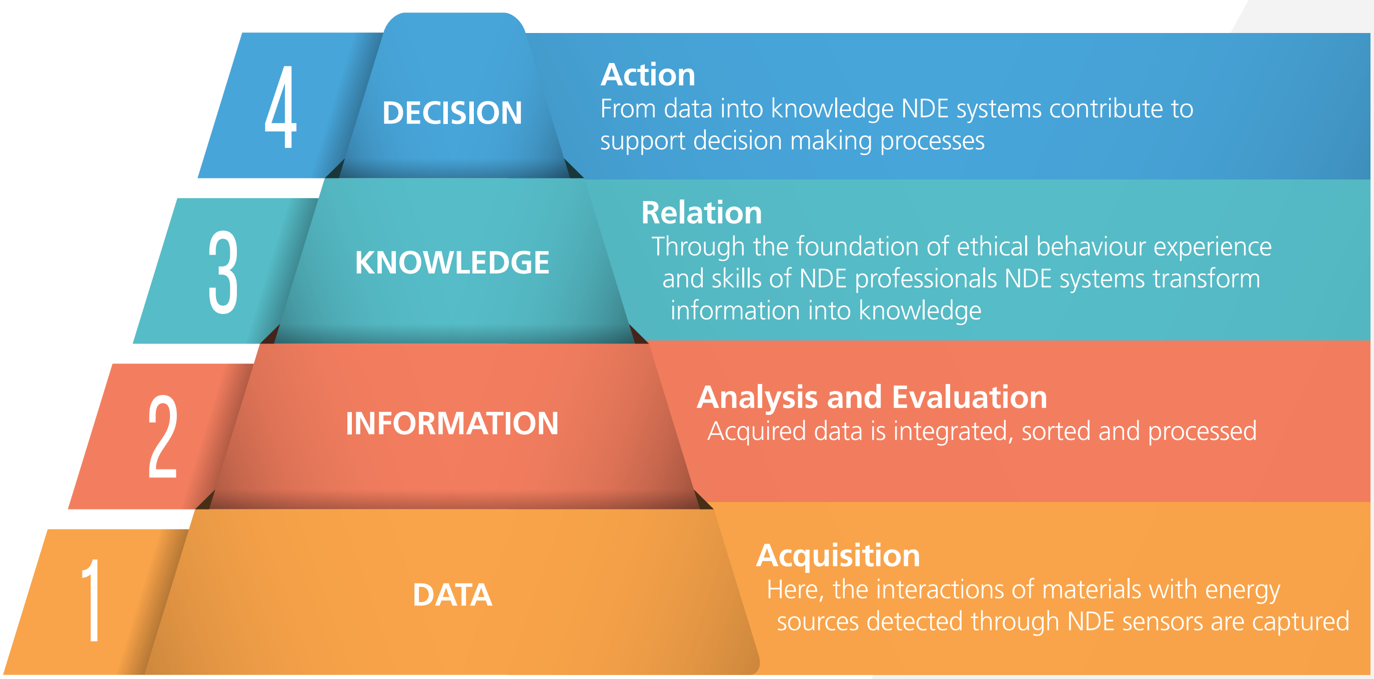

Figure 1- How NDE systems support decision making processes. Adapted by the Fernandez, Hayes and Gayosso [4] from Valeske [6]

Although the transition from film to digital radiography has been influenced by a series of factors related with industry specific requirements, there are also a series of other diverse factors that depend on the geographic or technological assimilation specific causes. It is evident that not only at the level of an individual company, but complete sectors are in the path of this transition.

Chakraborty and McGovern[3] reflect in how NDE revolutions are not chronologically synchronized with Industrial Revolutions but with groundbreaking innovations in the field; this includes the digitalization of recording media and innovations in information storage, data transmission, and post processing capabilities for visualization and analysis.

Chakraborty and McGovern[3] identify the following challenges that may limit the advancement in the deployment of digital technologies: ***Psychological Reservations*** including fear of change or fear of downtime during implementation; ***Infrastructural Limitations*** including elements such as legacy equipment that were not designed to fit in an interconnected ecosystem and ***Business Impediments*** such as requiring suppliers to provide more information in digital format or take extra steps to record all activities digitally.

A new "chapter" for Digital Radiography

To contribute, encourage and in support of the digital transition process, ASNT not only enriched, updated and expanded the most recent edition (4th) of the ASNT Nondestructive Testing Handbook: Volume 3, Radiographic Testing[2], but also prepared an updated revision of its Radiographic Interpretation Manual. The "Radiographic Interpretation, Revised Edition 2020" Manual[1] is organized in four parts. One of these parts is totally devoted to Digital Radiography, as in shown in **figure 2**, as a starting point for radiographers to familiarize them with the modalities of CR and DR.

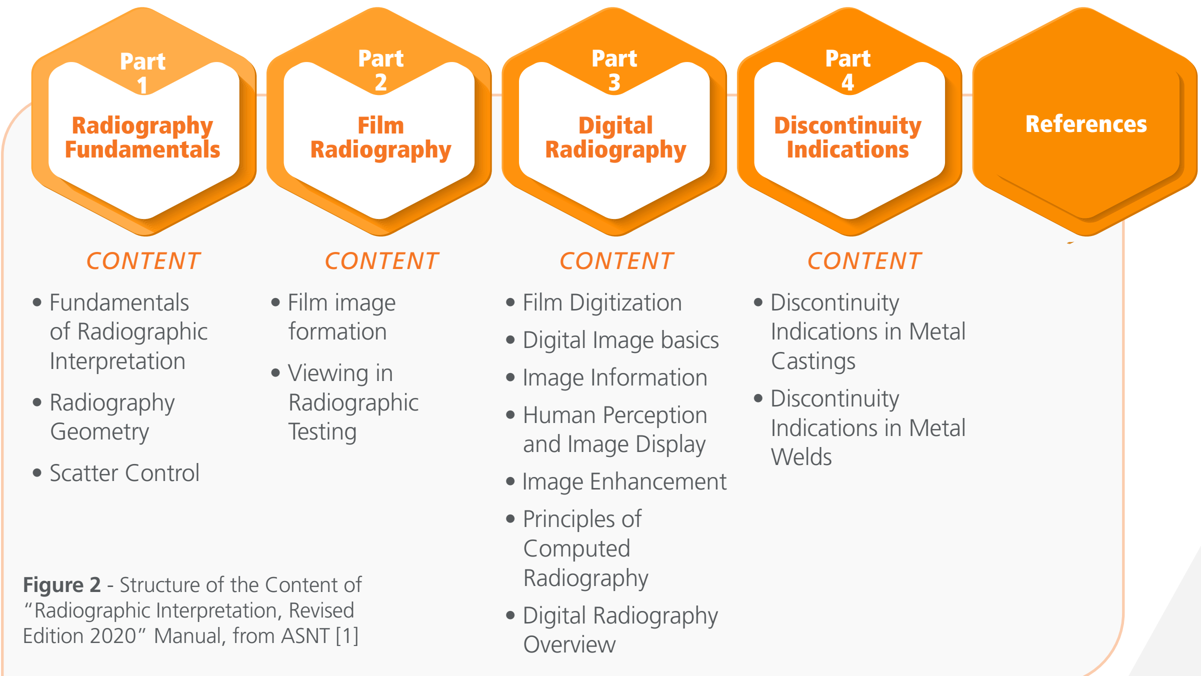

Figure 2 - Structure of the Content of "Radiographic Interpretation, Revised Edition 2020" Manual, from ASNT [1]

Radiographic Interpretation, Revised Edition 2020"[1] defines DDAs as *"a radiologic imaging device that converts ionizing radiation (x-ray or gamma ray) into analog signals, which are then digitalized and transferred to a computer for display. The energy deposited in each pixel of the array is directly to the grayscale level or pixel value in the resultant image"*. The manual also describes their structure and function as follows: *"Arrays may be linear, also referred to as linear diode arrays (LDAs), or two dimensional (DDAs). Both types may either directly capture photons of ionizing radiation (through the use of a photoconductor), or may indirectly capture those photons through the use of an intermediary phosphor (also referred to as a scintillator) material. The resulting charge or light is captured by a silicon pixelated readout structure"*. About, DDA's functionality[1] explains *"can range in speed from many minutes per image to many images per second, up to an excess of real-time radioscopy rates (usually 30 frames per second). DDAs can be used to enhance productivity as well as the quality of x-ray and gamma ray nondestructive testing. They are used as a diagnostic tool in the manufacturing process, for inline testing in production lines, and are used in-service."*

Radiography as science and craft

Obtaining adequate radiographic image quality is the result of the scientific principles that sustain the radiographic imaging process, and of the craft and experience that the radiographer possesses while developing an adequate radiographic technique.

In the case of digital radiography, besides the traditional factors associated with radiographic technique such as source to object distance or geometric unsharpness, new factors such as averaged frames, integration time, pixel intensity or contrast-to-noise ratio (CNR) shall be considered. **Figure 3.**

But regardless if the radiographer is using film, computed radiography (CR) or digital radiography (DR), it is common they refer to one of the most diffused radiographer adages: "Dose is King", highlighting the importance of selecting the proper amount of exposure that matches the rest of variables. Adequate exposure has a direct effect in radiographic image quality, including the image contrast that is achievable.

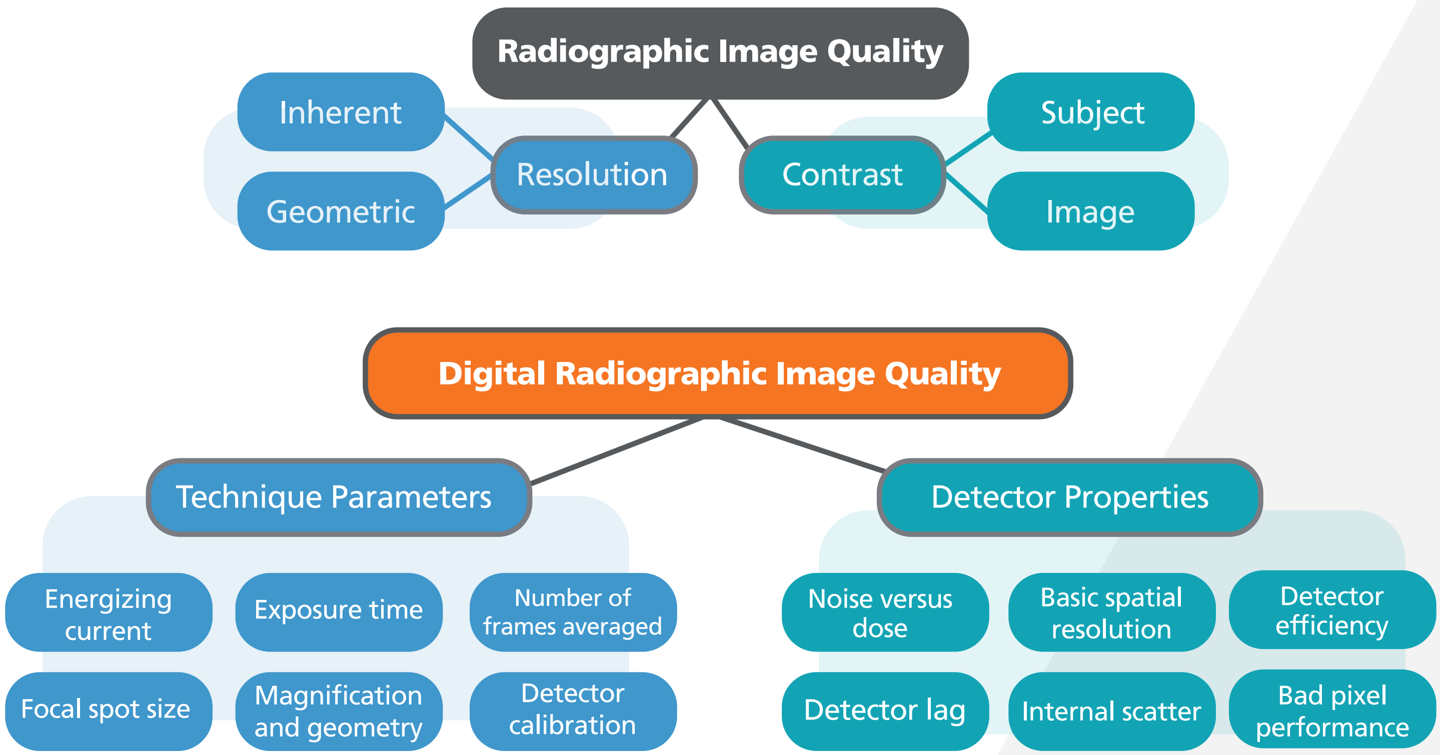

Figure 3 - Factors that affect radiographic image quality, from ASNT Nondestructive Testing Handbook: Volume 3, Radiographic Testing 4th Edition [2]

Debunking the myth of one-size-fits-all pixel intensity

As DDA systems are becoming more prevalent in industrial radiography, some myths surge. One prevailing myth while selecting DDA systems is that pixel intensity determines the contrast-to-noise ratio and detectability. Brian White, Research Scientist at Carestream, explains it in[7] the following terms: *"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. When the same pixel intensity has been obtained, it does not guarantee that the same contrast sensitivity has been achieved."*

In[7] White describes a series of tests he conducted using a Carestream NDT HPX-DR 3543 DDA, 139 µm image resolution, 139 µm pixel pitch, 14 x 17 inch (350 x 430 mm) active area DDA with both X-rays **(see Figures 4 and 5)** and gamma rays.

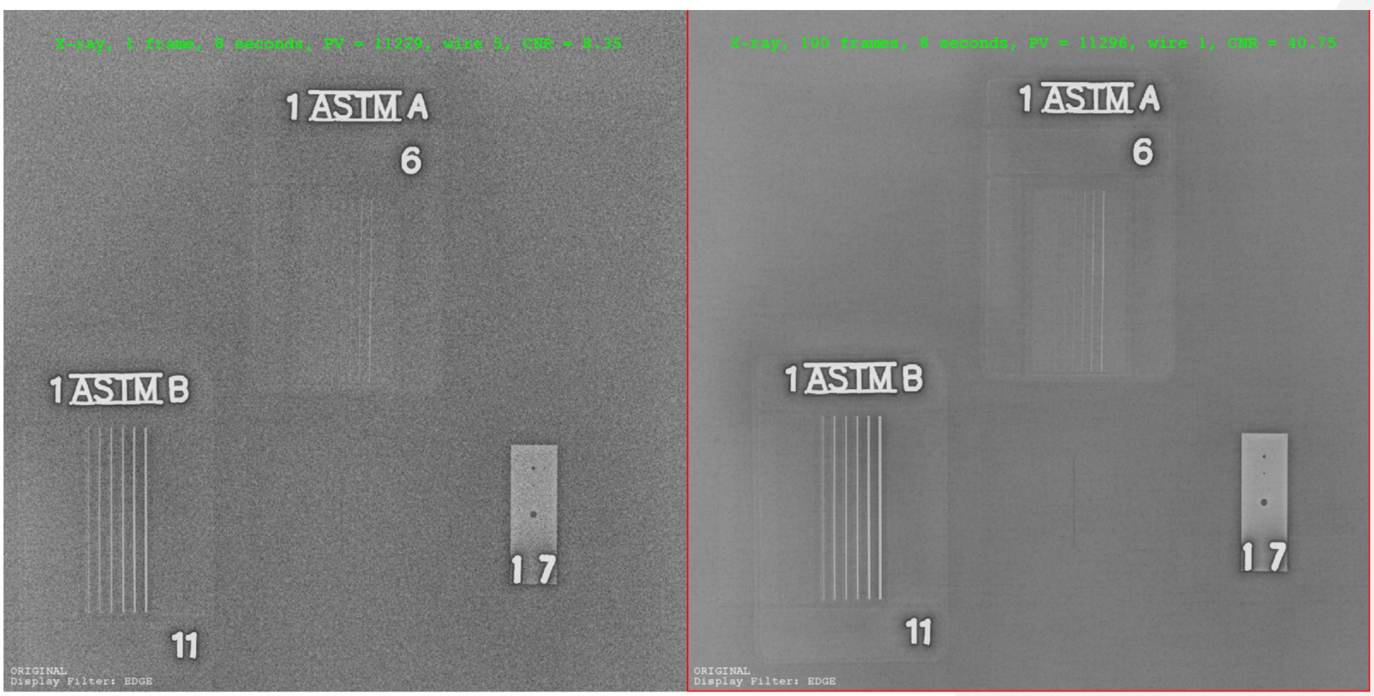

Figure 4: Comparison of Averaged Frames for the HPX-DR 3543. It presents a visual comparison of averaged frames for X-ray. The image on the left was at 1 frame, 8 seconds integration time, pixel intensity of 11229, 5 wire visible, contrast-to-noise ratio CNR of 8.35. The image on the right was at 100 frames, 8 seconds integration time, pixel intensity of 11296, 1 wire visible, contrast-to-noise ratio CNR of 40.75.

Even though the pixel intensities were virtually the same, the image quality for the image on the right was significantly better from White, B., Presentation "Exposure Guidance and the Myth of Pixel Value Dependence for Digital Detector Array Radiography" ASNT Annual Conference, Virtual, 2020. [8]

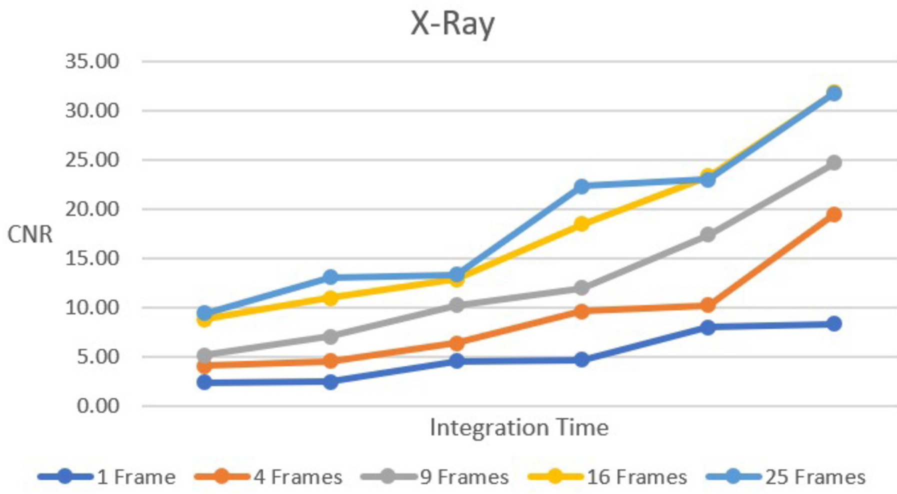

Figure 5: Improvements in contrast-to-noise ratio (CNR) for X-ray as integration time increases for several averaged frames for the HPX-DR 3543. From White, B., Presentation "Exposure Guidance and the Myth of Pixel Value Dependence for Digital Detector Array Radiography" ASNT Annual Conference, Virtual, 2020. [8]

In[8] White describes – along with the series of tests he conducted using the HPX-DR 3543 DDA described above – a new series of tests using a Carestream HPX-DR 4336 DDA, which has 100 μm basic spatial resolution, with a 14 x 17 inch (350 x 430 mm) active area DDA, with both X-rays **(Figure 6)** and gamma rays on a 2 inch diameter, schedule 80 (0.218 inch wall thickness) steel pipe. In this new set of tests, a new variable was tested due to this DDA's ability to adjust amplifier setting.

Figure 6: Comparison of adjustments in the amplifier setting for the HPX-DR 4336 DDA. Even though the pixel intensities are also virtually the same, the image quality for the image on the bottom is significantly better from White, B., Presentation "Exposure Guidance and the Myth of Pixel Value Dependence for Digital Detector Array Radiography" ASNT Annual Conference, Virtual, 2020. [8]

We encourage our readers to explore White's article on this subject at his presentation at ASNT's 2020 Annual Conference ***(which can be found here)*** and discover that pixel intensity by itself does not determine the contrast-to-noise ratio and detectability.

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

For readers interested in exploring how digital radiography (DR) 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

- **HPX-DR 3543 PE Non-Glass, Large Format Detector**
- **HPX-DR 4336 GH High-Resolution, Large Format Detector**
- **HPX-DR 2530 PH High-Resolution, Compact Detector**
- **HPX-DR 2530 PC High-Speed, Compact Detector**
- **INDUSTREX Digital Viewing Software**

Services - Training

Digital Detector Array Radiography - 40 Hour Online Course
Digital Imaging - 40 Hour Classroom Training

- **Advanced Industrial Radiographic Training Academy**

For radiographers using gamma rays, **Table 1** below provides a good starting point to explore the use of Carestream NDT's DDAs:

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 1: Digital R Factor for Carestream's DDAs

Adapted from White, B., Presentation "Exposure Guidance and the Myth of Pixel Value Dependence for Digital Detector Array Radiography" 20th World Conference, 2020. [8]

This table is available in PDF format in the following link:
https://www.carestream.com/en/us/-/media/publicsite/resources/ndt/other-references/r-factor-table-hpx-dr.pdf

Resources from ASNT:

- Radiographic Interpretation, Revised Edition 2020:
  https://www.asnt.org/Store/ProductDetail?productKey=826c3c22-42a3-4250-9040-913d40aa0946
- Nondestructive Testing Handbook, fourth edition: Volume 3, Radiographic Testing:
  https://www.asnt.org/Store/ProductDetail?productKey=83ea27b3-d68f-483d-9354-e447ef2b3915

References:

1. ASNT, (2020), Radiographic Interpretation, Revised Edition 2020 , Bossi, R. and Gordon, T. (eds), Columbus, OH, American Society of Nondestructive Testing.
2. ASNT, (2019), Nondestructive Testing Handbook, fourth edition: Volume 3, Radiographic Testing, Columbus, OH, American Society of Nondestructive Testing.
3. Chakraborty, D., & McGovern, M. E. (2019, June). NDE 4.0: Smart NDE. In 2019 IEEE international conference on prognostics and health management (ICPHM) (pp. 1-8). IEEE.
4. Fernandez R., Hayes K., and Gayosso F.. (2021) Artificial Intelligence and NDE Competencies. In: Meyendorf N., Ida N., Singh R., Vrana J. (eds) Handbook of Nondestructive Evaluation 4.0. Springer, Cham.
5. Trampus, P., Krstelj, V. and Nardoni, G., 2019. NDE integrity engineering-–A new discipline. Procedia Structural Integrity, 17, pp.262-267.
6. Valeske B., Lugin S. and Schwender T., (2021) The SmartInspect System: NDE 4.0 Modules for Human-Machine-Interaction and for Assistance in Manual Inspection, First International Virtual Conference on NDE 4.0
7. White, B., Article "Exposure Guidance and the Myth of Pixel Value Dependence for Digital Detector Array Radiography" ASNT Annual Conference, Virtual, 2020.
8. White, B., Presentation "Exposure Guidance and the Myth of Pixel Value Dependence for Digital Detector Array Radiography" 20th World Conference, 2020.