With the current technical advancements and the emergence of high-powered computers, sophisticated software, and most importantly the steady drop in prices, industrial radiographic testing (RT) is gradually shifting, though it is still a long way away from film radiography. Companies providing industrial radiography services now have two available choices: digital radiography (DR) and computed radiography (CR), which is a form of DR. While working on modernizing radiography practices, it is important for the user to carry out some basic research for choosing between DR and CR by weighing the abilities of each along with the needs of both the company and the clients. This article attempts to provide readers with a basic understanding of both DR and CR and covers the advantages and disadvantages of both. Furthermore, it provides readers with a comparison of both digital techniques and adds a comparison between digital (DR/CR) imaging and conventional film.

**Digital Radiography**

DR is a modern inspection technique that involves a detection system where digital radiation sensors are used instead of radiographic film. The application does not require the use of a cassette, and an image is displayed directly on the computer screen.

The main benefits include efficiency gains on film development time, because the costly chemical processing is eliminated, and the ability to digitally transfer and enhance the radiographic images. In addition, with the ability of radiographic enhancements, less radiation can be used to produce an image of similar contrast and definition compared to conventional RT.

Digital image capture devices give the advantages of immediate image preview and availability. The process consists of converting the radiation into an electric charge and then to a digital image using flat panel detectors (FPDs). FPDs are classified as a solid-state X-ray digital
device that is used for imaging. The resultant images provide a wider dynamic range, which makes it more forgiving for over- and underexposure, as well as the ability to apply special image-processing techniques that enhance the overall display quality of the image.

The two main classifications of FPDs are direct and indirect. Direct FPDs (Figure 1) are composed of amorphous selenium (a-Se), the most used material in commercial FPDs, which converts radiation photons directly into charge. The outer layer of the FPD is typically a high-voltage bias electrode. Radiation photons create electron-hole pairs in a-Se, and the transit of these electrons and holes depends on the potential of the bias voltage charge. As the holes are replaced with electrons, the resultant charge pattern in the selenium layer is read by a TFT (thin-film transmitter, a type of LCD flat panel screen) array, active matrix array, electrometer probes, or microplasma.

Indirect FPDs are manufactured by combining an amorphous silicon (a-Si) detector with a scintillator in the detector’s outer layer, which is composed from caesium iodide (CsI) or gadolinium oxysulfide (Gd$_2$O$_2$S), which converts radiation to light. This conversion makes the detector an indirect imaging device. The light is then channeled through the a-Si photodiode layer, where it is converted to a digital output signal. The digital signal is then read out by TFTs or similarly approved devices.

Advantages of DR include reduced exposure times, elimination of costly chemical processing, and reduced costs coupled with higher production rates. Inspection applications are faster. Insulation removal is not required, because of image enhancement capabilities. Images can be digitally stored, with the possibility of electronic transfer. With image enhancements, the image densities can also be altered in accordance with the inspection code requirements. The grayscale resolution is superior, and exposure failures are reduced, with possible software improvements applied to the captured images. The radiographic detail and image definition is higher, and produced images have a greater range of latitudes (up to 1000× greater than film). DR offers increased portability and reduced film artifact possibilities. DR shows a better sensitivity to environmental conditions than CR systems.

There are some disadvantages of DR. The technique requires high-end training, the lack of which can create undesirable performance and questionable results. Initial setup and start-up costs are higher. Image magnification, if not applied judiciously, can result in misinterpretation as the indications are altered from original sizes. Currently, spatial resolution (size of the smallest detail) is comparably smaller than conventional RT. FPDs are not indestructible; they are affected over time with the amount of radiation absorbed and the radiation energy levels, therefore needing to be replaced over time. FPDs at higher energy levels are subject to fading of the image known as ghosting, primarily caused by the incomplete collection of charges.

**Computed Radiography**

CR is an application of DR. DR and CR are similar, as they both contain a medium to capture radiation and both provide an image that can be digitally enhanced. The imaging does not require chemical processing. In DR, the radiation is emitted to a FPD without the use of a cassette, whereas in CR, radiation is emitted to an imaging plate housed in a cassette, similar to conventional RT. The cassette serves the purpose of protecting the imaging plate from light and related handling issues (Figure 2).

CR imaging plates contain photostimulable storage phosphors; these phosphors store the radiation as a latent image. As the image plate is scanned by a scanning laser beam, the release of stored energy within the phosphor is stimulated and emits light to be detected by a photomultiplier tube and converted to a digital signal using an analog-to-digital converter, which can be further intensified. The generated image can then be viewed on a computer monitor for evaluation.
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Imaging plates can be reused multiple times and may often result in damage after extended use due to the industrial nature of the RT field. The plates can be erased by exposing them to normal interior lighting, but most laser scanners automatically erase the plates by using the red laser light of the scanner. The image requires processing, almost immediately after exposure, to prevent the loss of image as the trapped electrons can return to a lower energy level.

There are several advantages to CR. Testing can be performed with insulations and coatings in place. There are no temperature limitations. CR has a very high sensitivity to corrosion and pitting and is able to generate accurate corrosion measurements. There are no chemicals or film required for processing. Image contrast and brightness can be modified. There are reduced storage costs.

Along with the advantages of CR come a few disadvantages. CR requires long preparation times before the radiograph can finally be viewed. The processing application takes about the same amount of time as conventional film. There is a risk of overexposure. Care and maintenance is on the higher side, and imaging plates are costly. The manual handling of cassettes presents the risk of film artifacts. CR is sensitive to scattered radiation, and there is a low signal-to-noise ratio.

**Comparison of DR and CR**

Both DR and CR use a medium to capture radiation energy, and a digital image is produced. CR uses imaging plates whereas DR uses detectors as the medium. DR uses less radiation energy to produce an image, which is formed within seconds of an exposure, making it faster than CR. CR is slower; the time required to remove the cassette from the tray, take it to the reader (or scanner), and clearing the same can take several minutes. CR can also provide less resolution with a similar radiation dose.

DR has superior quality compared to CR. The following is a summary list of comparisons:

- DR has a lesser requirement on radiation to produce a high-quality image and provides enhanced radiation exposure protection to radiographers.
- CR does not reach as high of a sensitivity as DR.
- DR has a wider range of latitude.

**Comparison of DR/CR with Conventional RT**

A short comparison between conventional RT with CR and DR is a must before even trying to advance a company into the world of digitalization. Following is a summarized list of major comparisons:

- DR and CR do not require physical film.
- Conventional RT has limited film latitude, whereas DR and CR images have up to 1000× greater latitude.
- DR and CR have faster exposure times (requiring 5 to 20× less radiation than conventional RT).
- DR and CR require no costly processing.
- DR and CR are not restricted by the temperature of the material under inspection.
- DR and CR produce less radiation exposure in a given time due to reduced exposure times.
- Performing DR with high-energy sources such as cobalt 60 is very efficient for thick valves and fittings.
- Transporting radiation images can be accomplished immediately through electronic transfer.
- Film densities can be enhanced to reduce any miscalculations resulting in reduced exposure failures.
- Both DR and CR have the benefit of easier, accessible, and less expensive archiving. They also provide access to share data through the newly evolving standard DICONDE, which conventional film does not.

Figure 2. An example of the imaging plates used in computed radiography (CR).
In industrial RT, certain inspections will require a specific technique and/or method. There are several factors, such as cost, time, and quality, that govern the selection of conventional RT, DR, or CR for field application. Not only are DR and CR faster than conventional RT, they both provide a greater range of latitudes when thickness differences are present with welds and other structural components.

As compared to CR, DR provides an image of higher quality and speed, but for field applications, the FPDs used in DR are not as suitable as the imaging plates of CR. FPDs are not as flexible and durable as the imaging plates, which are more industrial oriented with the flexibility of adapting to curved components. The major drawback associated with both DR and CR is the sensitivity, which is not as apparent as the very fine grain film of conventional RT.

Evaluation of an imaging system depends on size, shape, and flexibility of sensors, whereas the scan rate and performance of the imaging system is affected by the correct sensitivity (such as 8-bit versus 12-bit) and the pixel size.

DR provides an excellent source for performing radiography for informational purposes as it provides a quick and detailed image of the object examined. Figures 3, 4, and 5 show radiographic images of pipe before and after cleaning. In the “before cleaning” image, the radiograph depicts debris on the bottom of the pipe. When the radiograph is retaken after cleaning, the debris has been removed as shown in the radiograph (Figure 4). The third radiograph (Figure 5) is an optional inverted image for contrast comparison.

Corrosion evaluation is one of the major applications of CR. The following are some examples: in-service (on stream) radiography for corrosion/erosion in noninsulated pipes; internal and external corrosion under thermal insulation; erosion and corrosion adjacent to the welds;
scaling; concrete and castings inspection; and weld inspection.

Digitalization Software

One of the major components of radiographic digitalization, either digital or computed, is the software, which is often associated with a particular equipment/system manufacturer. Though the software is of a proprietary nature, they all follow the same ASTM standards for digital imaging and communications in nondestructive evaluation (DICONDE) (ASTM 2015, 2018a, 2018b, 2020). The standardization of radiograph digitalization provides users with a portability between different equipment and software platforms, without compromising the details and related information. The DICONDE standard is backward compatible, which will also allow consumers to archive their films (digital radiographs) for many years to come, and all details, such as part, technique, and user information associated with the disposition (accept/reject) are retrieved without compromise.

The data retrieval will require authentication when communicating between DICONDE-compatible software platforms. The basic pixel data will never change; only the overlays can be altered. It is always recommended to refer to manufacturer instructions and be trained by a competent qualified technician prior to operating the DR equipment and associated software.

With the pursuit of NDE 4.0 as part of the fourth industrial revolution, the industry will see a very diverse digitization of NDE applications, systems, and software. Other DR advancements in medical technology have worked their way into the industrial applications, such as computed tomography (CT). We are only in the early stages and will witness further groundbreaking technologies with the use of artificial intelligence, smart NDE, and DICONDE (Figure 6). Regardless of the number of advancements in technology, the industrial radiography specialist will always be required to support all DR applications and its software.

**AUTHOR’S NOTE**

This article is a summary of Unit 31 from A Practical Field Handbook in Industrial Radiography & Radiograph Interpretation (G.W. Jaques and A.U. Rehman, 2019, published by Jaques Enterprise Inspection Inc. & EQIP Plus Publication). All content is used with permission.

**ACKNOWLEDGMENTS**

The authors would like to thank Abdulaziz S. Al-Neshamah, Inspection Department, Saudi Aramco, Saudi Arabia, and Ian Winter, Metalogic Inspection, Canada, for their help and support in producing pictures included in this article.

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**Digital Extra:** Visit the authors’ YouTube Channel “RTFIPro,” which provides a range of educational videos on the topic of industrial field radiography.
Description of AE Method

Acoustic emission is a sudden, transient release of energy that takes place due to material deformation, structural failure, or similar. Acoustic emission is similar to when rock formations crack in natural seismic events. This release is of short duration. The extent or amplitude of the transient release is measured on the Richter scale from 0 to 10, and the major difference between seismic and acoustic emission events is the frequency spectrum. For seismic, it is in the region of 0 to 60 Hz (cycles per second), whereas the frequency spectrum for acoustic emissions is most commonly between 20 and 1000 kHz.

If an analysis of the frequency spectrum for the seismic event is performed, it is noted that the frequency is broadband. The seismic industry is required to detect earthquake events over long distances. Physics prove that the greater the distance, the greater the attenuation (absorption) of the energy that takes place at higher frequencies; hence the use of low-frequency sensors. AE, as it is commonly called, is used in industrial applications, which makes it impossible to distinguish the different noise sources at these low frequencies. However, in AE the distances between the sensors rarely exceeds 30 m, so the use of high-frequency sensors is an advantage. By using high-frequency sensors and removing the low-frequency unwanted or nonrelevant noise sources with bandpass filters (first utilized in the early 1960s), the acoustic emission signals can be detected while in the operating environment.

Computer Analysis

High-speed computers and improved software have made it possible to closely examine the acoustic emission waveforms and to perform signature evaluation with greater accuracy.

Since the inception of AE in 1968, there have been tremendous advancements in computer technology and software, which in turn has influenced the use of acoustic emission signature recognition techniques and data collection speeds. For example, because the data capture and resolution in 1986 took approximately 100 milliseconds (ms), it was difficult to record all the transients. By comparison, in 2001 data could be collected at a rate of 250 nanoseconds (ns) and gigabytes of data could be stored instead of only 120 MB. This vastly improved the technology and reliability of this NDT method.

Figures 1 and 2 depict a typical AE setup with the corresponding signal data reported by AE analysis software.
The total purpose of this article is to look at the key features of the waveform along with the major factors that must be considered when interpreting the AE signal data.

Measurement of the Acoustic Emission Signal

The common practice in AE is to quantify and record the digitized waveform of the acoustic emission signal, or “hit.” To do this, the analog response from the AE sensor is recorded with the following features of the waveform (see Figure 3):

- Amplitude: the maximum voltage amplified through a preamplifier. The range is 30 to 100 dB AE.
- Rise time: the time in microseconds (μs) from the first threshold crossing to the peak amplitude.
- Duration: the duration of the hit in μs from the first threshold crossing to the last crossing.
- Energy: the measured area under the ring down height response curve (labeled “D” in Figure 3); it uses the formula $\int \frac{v}{dt}$, also referred to as marse or signal (where $v$ = voltage and $dt$ = Delta time).
- Strength (most data-collecting software uses the term “energy”).
- Counts: the number of threshold crossings. (This is related to frequency and is not normally used by the author in evaluation.) The higher the frequency of the AE sensor, the greater the count for the same hit recorded.
- Average signal level (ASL): the mean or average signal level measured in dB AE, used to quantify leaks and mechanical rubbing.
- Threshold: the setting used to eliminate unwanted noise levels, similar to the reject level used in ultrasonic testing (UT). The higher the threshold, the lower the detection level. In normal AE, this is set at 40 dB for data collection and raised to 50 dB for evaluation purposes.

Effects of Materials on the Acoustic Emission Signature

When using standard AE data collection techniques, it is important to know as much as possible about both the history of the structure and the material used in its construction. The material properties affect the acoustic emission signature in a few ways, and those properties can be modified by age and load history.
When designing a structure, the materials selected are chosen for their specific properties, which enables them to meet the operational requirements for a specific operating environment. Factors to consider include operating temperature, resistance to corrosion, ductility, fracture toughness, and maximum design loads. It is important to understand how each of these factors affect the acoustic emission signal response. Because the material properties play an integral role in the acoustic emission signal that is generated, it is critical that the data is not analyzed using established “norms” from generic studies of other random samples of the same material. The properties of materials can change over time in response to various environmental factors, so the more information that is known about the history of the structure, the more accurate the AE data analysis will be. If the results of other studies are to be used in the analysis, the data should be taken from samples that share the same history of usage and environmental factors.

One historical factor that is sometimes ignored is the age of the structure. A number of very useful studies have been conducted to determine the fracture toughness of a particular type of material. Most of these studies have been done on virgin material that has not experienced any fatigue loading. In these studies, the structure is loaded once to remove or neutralize residual stresses, and then the structure is loaded a second time for evaluation (ASME 2019a, 2019b; Fowler et al. 1989). While this is an effective method for determining the fracture toughness of a material sample, the data obtained from the virgin material cannot be applied generically to a structure that has undergone stress loadings over time. Materials that have undergone significant stress changes for any reason will develop metal fatigue, and the acoustic emission signature as well as the fracture toughness will change.

Another historical factor that must be considered is the structure’s load history. The Kaiser effect is an acoustic emission phenomenon defined as the absence of detectable acoustic emissions until the previously applied stress level is exceeded. The Kaiser effect is well described in many of the early papers on AE. Briefly explained, this is the irreversible effect on the structure being tested. This effect can, however, be nullified by temperature and metal fatigue due to operating conditions. For this reason, it is strongly recommended that the test load be based on the history of the structure. As a guide, the test load should be at least 5% higher than the highest operating load or pressure that the structure has seen over the last six months (this information can be obtained from the operational records of the structure).

The basic crack behavior can be categorized into three major sectors: initiation, subcritical growth, and catastrophic failure. Each stage has its own distinct acoustic emission hit signature (Figure 4).

Crack Initiation

Crack initiation is illustrated in the first stage of Figure 4. Cracks may start for several reasons. Among these are corrosion pitting, mechanical damage, defects in the base metal or weld, and metal fatigue. The acoustic emission hit signature may be small or large depending on the brittle state and fracture toughness of the material. For example, the acoustic emission waveform for normal pressure vessel steels that have seen service is likely to show an amplitude in the region of 60 to 70 dB and energy level of 60 to 100 (for a reference gain of 23 dB) for sources close to the AE sensor. (The farther the distance between the sensor and the source, the lower the levels will be.)

Subcritical Crack Growth

Subcritical crack initiation is illustrated in the second stage of Figure 4. The incremental growth of the crack is a step function. During this phase, the energy usually increases as the crack approaches the catastrophic phase. Practical AE tests show an increase in both the energy and the amplitude of the acoustic emission hit. It is exceedingly difficult to be specific as to what the values will be, as this again is influenced by the material. For common pressure vessels (steels), at a given distance early in the subcritical stage, the AE values are likely to be higher than 70 dB AE with an energy level greater than 100. Closer to the catastrophic phase, the AE value will be between 80 and 100 dB with an energy level exceeding 250. One good indicator is when the hit/energy ratio exceeds 250; then it is time to examine the structure in the area near the AE sensor using other suitable NDT methods such as UT. Another good indicator that the structure is in trouble is the increase in the level of acoustic emission hits recorded during the procedural hold periods (normally 10 min during 50%, 65%, and 85% of the pressure load, and then 30 min during the final test load).
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Catastrophic Failure

An example of catastrophic failure is shown in the final stage of Figure 4. In this phase, the structure is no longer able to retain its form and could lead to serious damage. This phase is to be avoided as much as possible due to economic impacts and safety issues.

Evaluation by Material Type

Following are some of the important characteristics or conditions that play a role in the acoustic emission signature evaluation process by material type. This information is based mostly on “in the field” experience and verification of AE results.

- **Steel**: strength, fracture toughness, ductility, age, presence of residual stress, presence of weld defects, and temperature.
- **Austenitic steel**: strength, fracture toughness, ductility, age, presence of residual stress, presence of weld defects, and temperature.
- **Composite structures**: this includes materials such as fiber-reinforced plastic (FRP) and concrete. The failure mechanisms of FRP include fiber breakage, delamination (debonding), and matrix cracking, while the failure mechanisms of concrete include alkaline damage cement cracking and the like.
- **Cast iron**: there are two major types of cast iron—spheroidal graphite (SG) and gray cast iron. The SG cast iron is more ductile than the gray cast iron. When testing cast iron, it must be noted that this material is more brittle than the steels used in pressure vessels and therefore the acoustic emission signals are going to be much higher. A small crack will record activity in the order of +80 dB.

In Part 2 of this article, the influence of the various materials used in construction and their effects on the AE data will be discussed.

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Practitioner Profile

Roberto Arenas Tuxpan

Roberto Arenas Tuxpan is a digital nondestructive testing (NDT) trainer and third-party inspector located in Ciudad del Carmen, Campeche, Mexico. Originally a welder, he became interested in NDT after his first time seeing an ultrasonic flaw detector in action. Today he works for his own company, PNDS MÉXICO.

Q. How did you first become involved in NDT?
A. I heard about NDT at school when I was studying industrial welding in 2006. At the beginning it was something of little relevance to me at age 18, but when we had practical workshops and I saw for the first time an ultrasonic flaw detector, everything changed; I was interested in knowing more about the subject of ultrasound. I requested documents on the subject from my teachers, and they shared Article 4 of ASME BPVC Section V. Two years later, I got a job opportunity as a student intern and trainee in a company that conducts NDT in the field for different industrial sectors.

Q. Can you tell us about your certification and training?
A. My NDT training was provided by an in-house ASNT NDT Level III and combined with on-the-job training given by my coworkers who were Level IIs (today they are also Level IIIIs). I was lucky to gain practical experience onsite in different industrial sectors and with different NDT techniques. One day of the week you would see me inspecting new nuts and bolts with wet fluorescent particles; another day I was traveling to inspect forgings or castings for automotive parts with visible liquid penetrants; and at the end of my week, I was inspecting with ultrasound angle beam welds in pipes and pressure vessels for food and beverage processing.

After three years of continually performing onsite inspections as a Level II technician, my mentor and friend Bonifacio Alanis Toledo offered me financial and technical help to study and prepare for my first certification as an ASNT NDT Level III. Today I have five NDT Level III certifications in VT, PT, MT, UT, and RT. I am also an AWS Certified Welding Inspector and a Rope Access Level I IRATA technician. Next, I am planning my API 570 certification as a pipe inspector.

Q. Is your work focused on a particular field?
A. Currently my work is focused on the oil and gas industry in offshore and onshore facilities to comply with standards such as AWS D1.1, ASME B31.3, ASME BPVC, API 1104, API 650, and other related documents.

Q. Describe your working environment.
A. Today I work for my own company called PNDS MÉXICO, offering digital and traditional training services in different NDT methods as well as onsite third-party inspections. I work with a small team of Level IIs (Alexandra Zavala, Eric Montes de Oca, and Anibal Vázquez), and our mission is to inspire the new generation of NDT and welding specialists.

Some days we have fun in the office recording videos/audio or writing articles to share on social media. We develop technical NDT procedures, trainings, and examinations at the customer’s facilities; other days we travel to workshops or plants to perform third-party inspections or witness the qualifications of welders.
Q. Tell us about your work in training NDT personnel. What characteristics do you think define a good NDT technician?
A. In my company we are changing from providing traditional training to a hybrid version of watching videos, listening to audio, and answering dynamic tests on a 24/7 e-learning platform.

I believe that the characteristics of a good NDT technician should be a balanced combination of passion for NDT, theoretical knowledge, practical ability, interpretation of standards, and knowing their own way of learning so they can seek that version of training.

Q. What advice would you offer to individuals considering careers in NDT?
A. First, welcome everyone. I recommend that they analyze the type of job they want; NDT offers several categories or positions in which we can contribute to the quality and safety of our society. For example, they can be Level II field examiners, Level III consultants, trainers, auditors, inspection equipment developers, NDT bloggers, podcasters, and so on. NDT offers challenges and potentially unlimited growth, and I can assure you that the more you learn, the more you want.

Q. Would you share with us a professional bucket list item?
A. Of course, it is very broad, but here are some things I want to do during my NDT career: write a beginner’s book; perform a nondestructive underwater test (diving); perform NDT with rope access on a wind tower; inspect rocket parts; meet the officers of leading NDT societies worldwide, such as ASNT; and offer free training to young people who cannot afford to pay.

Q. Do you have a favorite quote that inspires your work or personal life?
A. When I was studying for my first ASNT exam in 2011, I read a phrase in the Handbook of NDE: “In NDT there is no room for those who are just doing their job.” That quote had an impact on me and has inspired me all these years.

You can reach Roberto Arenas Tuxpan at gerencia@pndsmexico.com.

Correction
In the Practitioner Profile of Cat Stravino in the January 2021 issue of The NDT Technician, it was incorrectly stated that Stravino attended Ridgewater College in Willmar, Minnesota. She actually attended the Ridgewater College NDT program in Hutchinson, Minnesota (go Hutch Pups!). The NDT Technician regrets the error.