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Digital Radiography

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Pipe Inspection with Digital Radiography

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Pipe Inspection with Digital Radiography

Digital Radiography or DR is an advancement of traditional Radiography. This technique utilizes DDAs (Digital Detector Arrays) instead of Film or CR (Computed Radiography) in order to create an instant Image. The Radiation reaches the DDA, which has passed through the object, converted by a Scintillator into visible light and then translated into a digital Image. The physics (Angles, Penetration, technique etc) remain similar and only mild changes are required to make the transition to Digital Radiography.

Why do we inspect Pipes?

Pipes, whether in service, in production or during installation, have a variety of potential problems which can lead to failures. Typical inspections of pipes are performed in order to inspect the welds, measure wall thinning, Corrosion and clogging due residue build-up.

What would I gain by using Portable DR for pipe inspection?

The advantages are enormous in almost every aspect. Starting with the time needed to acquire an image, from setup until the interpretation stage, no need for returning to site for re-shoots, the added safety due to significantly lower dose and exposure time and the fact that consumables no longer take part.

It is no longer necessary to use neither a Dark room nor Chemicals with this technology.

Where are Pipe inspections performed?

Inspections are mainly done at the facilities where the pipes are in service; In the Oil and Gas Industry we are talking about all the stages of Midstream and Downstream operations, hence starting from the Transportation stage of the Crude Oil (or Gas) up until the final product is produced. Locations could be around Oil wells, in Refineries and in Power generation stations.

Do I need to use special sources of Radiation with DR?

No, all the sources of Radiation (X-ray and Isotopes) which currently exist at your workshop are suitable for use with DR. In fact, with Isotopes you are now able to extend the life cycle since DR requires lower activity (ci) thus replacing them less frequently.

Are there any DR standards for Pipe Radiography?

Yes, the main one being the European ISO 17636-2, and the well known ASME Section V (article 2) which permits the use of DR with mild modifications to the inspection technique.

One of the most problematic parameters to "convert" was Film Density. Due to the fact that with DR there is no equivalent parameter (the closest is Grey levels) other methods had to be developed in order to verify the image quality. Some of these are: SNR (Signal-to-Noise Ratio) and CNR (Contrast-to-Noise Ratio).

In a nutshell, ASME Section V states: qualification of the digital radiographic system requires a demonstration of the image quality indicator (IQI). The demonstration of the IQI requirements shall be considered satisfactory evidence of compliance with the procedure. In other words, no changes need to be applied to the technique.

The ISO 17636-2 requires, in addition to the Wire type IQI, a Duplex Wire IQI in order to measure the Basic Spatial Resolution (BSR). The Standard also requires measurements of the SNR (Signal-to-Noise Ratio) and CNR (Contrast-to-Noise Ratio) both of which are included in our software.

Would the fact that Digital Panels are rigid affect the image quality?

Being rigid has absolutely no effect on Image quality however, it does have an effect on the number of shots for medium size Pipes. For small bore pipes we need to take two shots just as with Film. In large diameters, the curvature of the pipes does not cause significant effect on the un-sharpness (Ug) in the Image therefore the number of shots remain the same. Moreover, Digital Radiography standards such as ISO 17636-2 state the same number of shots as with Film.

Just as with conventional Radiography, Pipes are inspected for three main purposes:

- ***Corrosion monitoring***
- ***Weld quality*** *(looking for Cracks, Gas inclusions, Porosity, lack of penetration etc)*
- ***Wall thickness*** (*Wall thinning)*

Corrosion monitoring is the most common application of Radiography. This is done mostly on pipes which are In-service as opposed to during production which requires inspections of the pipes' welds. Corrosion monitoring with DR is done in the same manner as with conventional Radiography i.e. same source of Radiation, Angles, Energy, Distance etc. However, there will be substantial exposure time reduction due to the dose sensitivity of the Detectors.

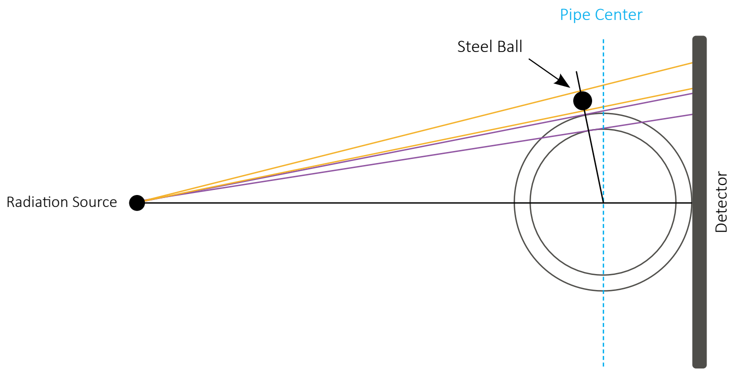
Weld quality is also done in the same manner as with conventional Radiography, just with the addition of IQIs (Image quality indicators) for verifying the Image quality requirements (in corrosion monitoring this is not required).

As for ***Wall thickness***, we differentiate between two techniques:
Tangential Technique and ***DWT*** (Double Wall thickness) ***Technique***.

It is worth mentioning at this stage that the main radiation sources which are used for ***Wall thickness*** measurements are Iridium 192 and Selenium 75 and less frequently Portable X-ray sources.

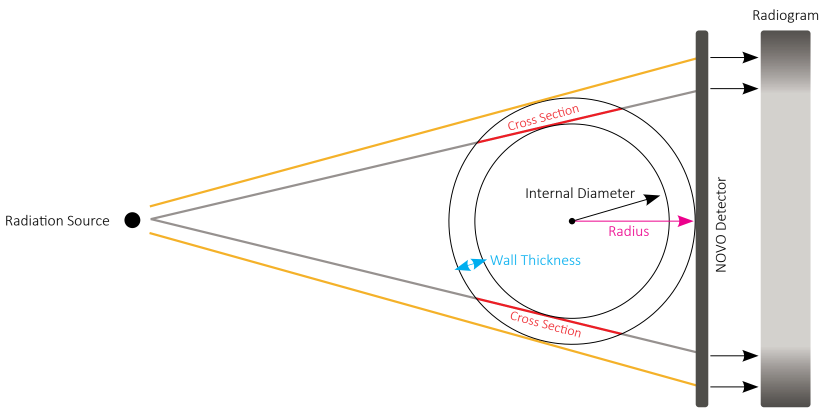
● *The Tangential Technique*

This is a straight forward and very much the same as with conventional Radiography.
The Pipe is positioned in-between the Detector and the source of Radiation, the Radiation passes through Pipe and reaches the detector thus forming an image. Then, using any object of known size (either an introduced item such as a steel ball or the pipe's nominal OD), the image is calibrated in order to disregard the geometric magnification which affects the measurement.



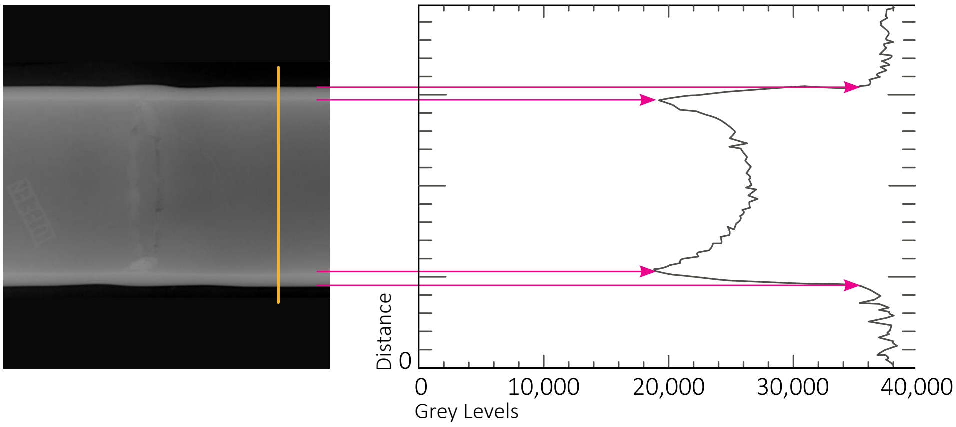
When performing wall thickness measurements in the Tangential technique it is often thought that only the wall thickness (t) needs to be penetrated. In reality, the material thickness which needs to be penetrated is much more than just the wall thickness. Looking carefully into the diagram below, we will see that the radiation needs to pass through not just the outer edges of the pipe (orange line) but also through the cross Section (Red line) also called L_{max}. This distance that the Radiation has to pass is substantially longer than just passing through the Pipe's wall. For example, a 100 mm OD pipe with just 3mm wall, leads to a cross section of ±34mm (!).

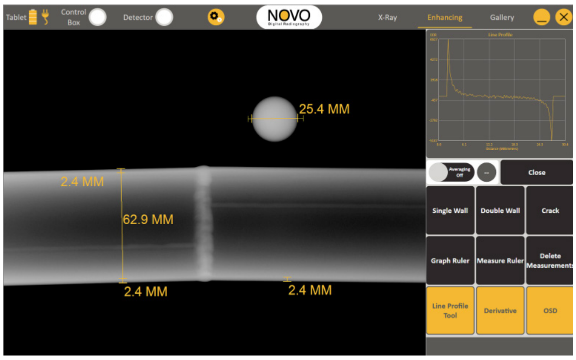
This technique is mostly done with Isotopes since there is a need to penetrate a lot of material even with thin walled pipes.
In the figure below we can see a typical setup of the tangential technique; in the Radiogram we can see the differential darkening according to the penetrated material in each area of the pipe.

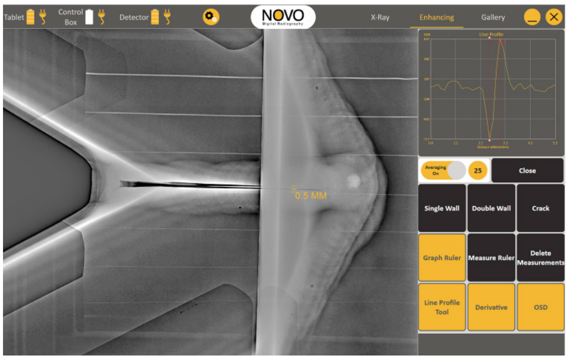


- ***Line profile tool***

A Line profile plots a chart of grey levels vs. distance; then, our unique wall thickness measurement tool automatically detects the Inner wall and outer wall using a highly accurate software algorithm which does not depend on visual measurements of the operators thus eliminating inconsistencies between operators. With the Automatic measurement tool the technician can easily perform high accuracy measurements with one or two screen taps. A line profile is stretched over the Pipe or Defect and with a simple tap, the software will automatically detect the edges of the Defect or, the end & start of the walls thus providing the user with the distance between them (which is actually the wall thickness of the Pipe or the width of the Defect).



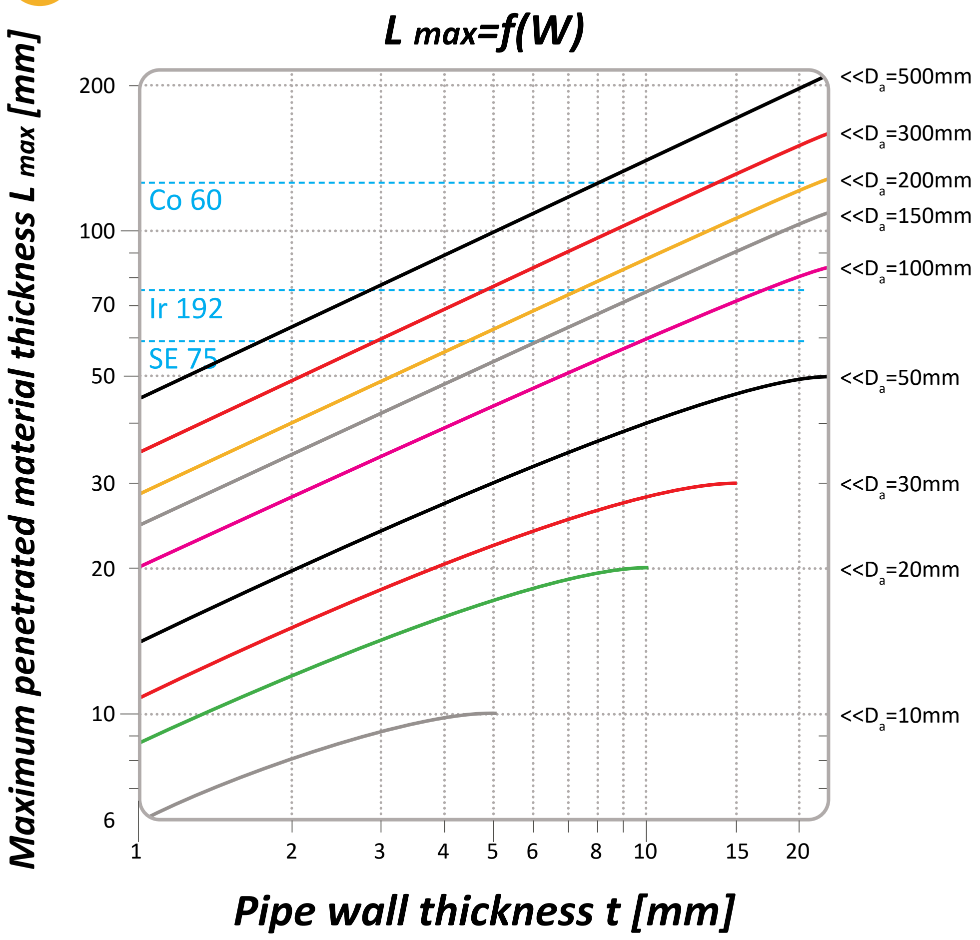




As opposed to conventional Film Radiography, with DR we are able to utilize a safer alternative to Isotopes (for thin walled Pipes) which is a Pulsed X-ray source. This is mainly due to the dose sensitivity of the Detectors which require a lower dose / energy compared to conventional Film Radiography. However, using an X-ray source for wall thickness measurements requires applying a slightly different methodology due to the differences between the Spectrum of an X-ray source and the Spectrum of an Isotope. Using an Isotope usually requires only one exposure in order to visualize the inner wall while not "burning" the outer wall; using an X-ray source requires taking two shots at two different exposures (low exposure and high exposure) since it is not possible to visualize the inner wall without "burning" the outer wall. In other words, with an X-ray source we will take a low exposure "shot", in order to see the outer wall, and a high exposure "shot", in order to see the inner wall. These two images are then combined, processed and presented as one easy-to-interpret image.

Below is a chart (A) which explains the limitations of the Tangential technique.

Chart A



Zscherpel, Ewert, Federal Institute for Materials Research and Testing (BAM), Berlin, Germany

First Research Co-ordination Meeting, IAEA, Wien, Nov. 2002

On chart B we are able to see a few examples of achievable penetration using various energies/ sources. These charts were originally calculated with Film but it gives us a good idea of the achievable penetration with DR as well. Let's take a look for example, at the achievable penetration of IR-192. It is known (and seen on chart B) that IR-192 can penetrate up to ±75mm of Steel.

Chart B

Energy: L max

100 kV: 10 mm
200 kV: 30 mm
300 kV: 40 mm
400 kV: 50 mm
Se-75: 60 mm
Ir-192: 75 mm
Co-60: 120 mm

Now let's look at chart A and do a simple example; starting from the 75mm point (Y-axis) we pull a line until we hit the orange curve (which represents 200mm OD); from there, dropping a 90 deg line to the bottom, we reach ±7,5mm wall thickness. This means that that with Ir-192 and a 200mm OD pipe the maximum wall thickness (t) which can be penetrated is ±7,5mm.
We can again take a look at the 75mm point and this time locate it at the intersection with the grey line (which represents 150mm OD); in this case the maximum wall thickness which can be penetrated is 10mm.
In both examples above, the Lmax stays the same at 75mm and as noticed, it's actually a trade-off between OD and wall thickness.
With the help of chart A we can see many combinations of OD and wall thicknesses which assist us in understanding penetration limitations and thereby the limitations of Tangential Radiography.
Alternatively, rather than using the chart, it is possible to use the formula bellow to calculate the Lmax or any other parameter which appears there (as long as minimum of 2 parameters are known).
In order to calculate and realize the actual thickness for visualizing the internal pipe wall (and thereby performing accurate wall thickness measurements) let's take a look at the formula given below:

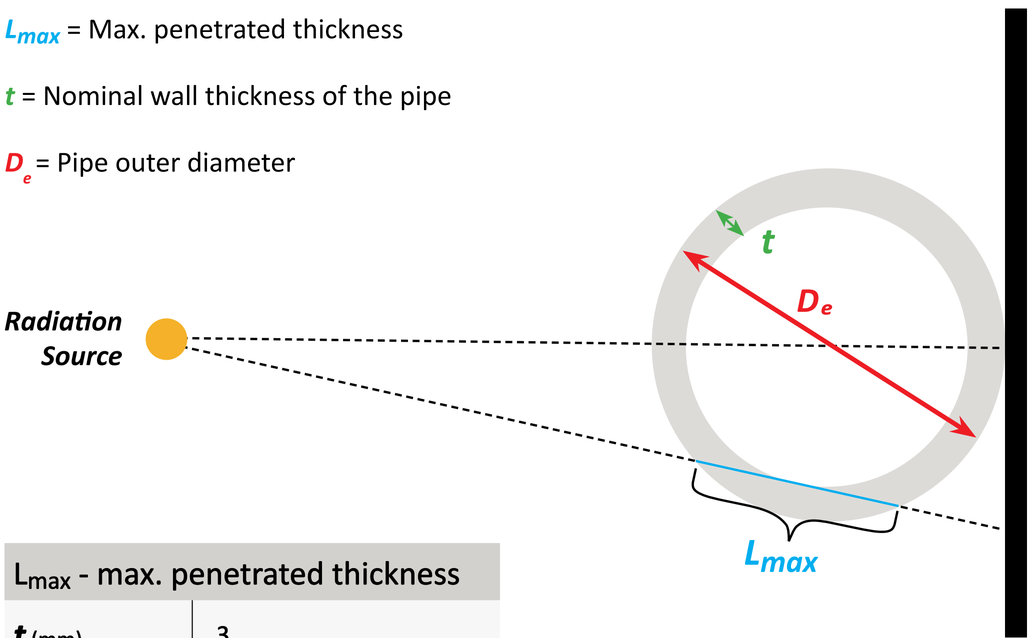
$$L_{max} = 2 \cdot \sqrt{t(D_e - t)}$$

Where:

L_{max} = Max. penetrated thickness

t = Nominal wall thickness of the pipe

D_e = Pipe outer diameter

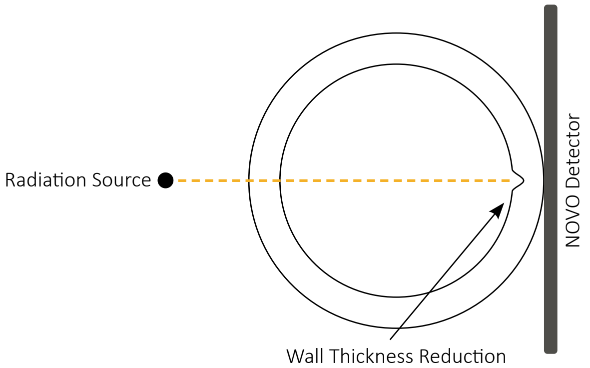


L_{max} - max. penetrated thickness	
t (mm)	3
D_e (mm)	101.6
L_{max} (mm)	**34.40**

Example of a 4" (101.6mm) Outer Diameter Pipe with 3mm wall thickness

- ***The DWT*** *(Double Wall thickness)* ***Technique***

The DWT technique is complementary to the Tangential technique. When having thick walled pipes it becomes difficult to perform wall thickness measurements due to the very large cross section (Lmax) which needs to be penetrated. The DWT technique requires penetrating only twice the wall (front and back) thus allowing using lower Energies and/or lower exposure times



With this technique we actually convert grey levels into material thickness (mm or inch) as opposed to counting the number of pixels in the Tangential Technique.

When using DWT Technique we must know or calculate the absorption coefficient (μ) which is specific for each material as a function of the energy (kV). Below is the general equation which the technique is based on:

$$I = I_0 e^{-\mu x}$$

I = the Radiation intensity transmitted across distance x

I_0 = the initial Radiation intensity

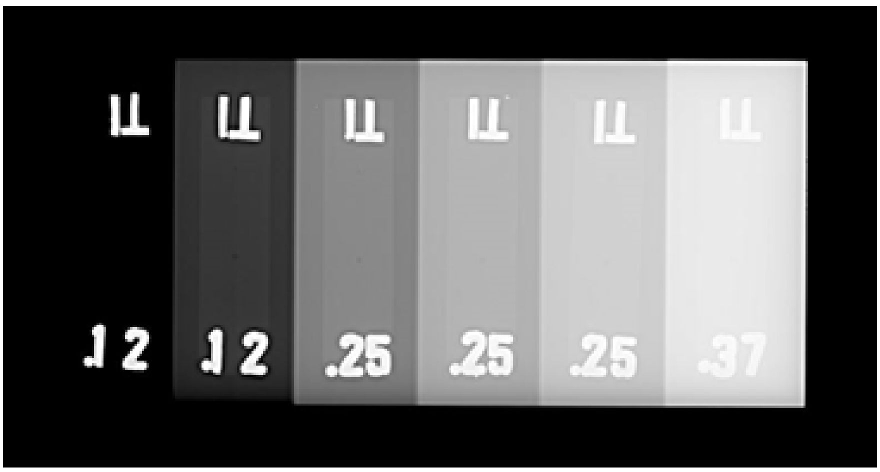
μ = Attenuation (absorption) coefficient

x = distance traveled

This is less complicated than it seems since the software will do the calculation for us (with a little bit of our help).

We have two options for calculating the absorption coefficient (μ):

1. Using a step wedge of at least two steps, made of the same material which our inspected item is made of:



2. A pipe made of the same material which our inspected item is made of, with a through hole (drilled) in one wall:

The grey level in the area around the hole represent twice the wall thickness while the grey levels inside the hole itself represent one wall.

With both options 1 & 2 above, we will use the simple DWT tool in our software to point out the two thicknesses and the software will calculate the attenuation coefficient. After this simple step we simply have to point the cursor in the area we would like to measure and a measurement will be presented to us, either in absolute values or reduction in percentage.

Summary

- Digital Radiography using DDAs provide many advantages compared to other detection Medias
- DDAs require a substantially lower dose / energy compared to conventional Film Radiography
- DDAs enable utilizing Pulsed X-ray sources which are a safer alternative to Isotopes (for thin walled Pipes)
- In order to perform wall thickness measurements in a variety of Pipe sizes two techniques can be applied: Tangential Technique & DWT (Double Wall thickness) Technique

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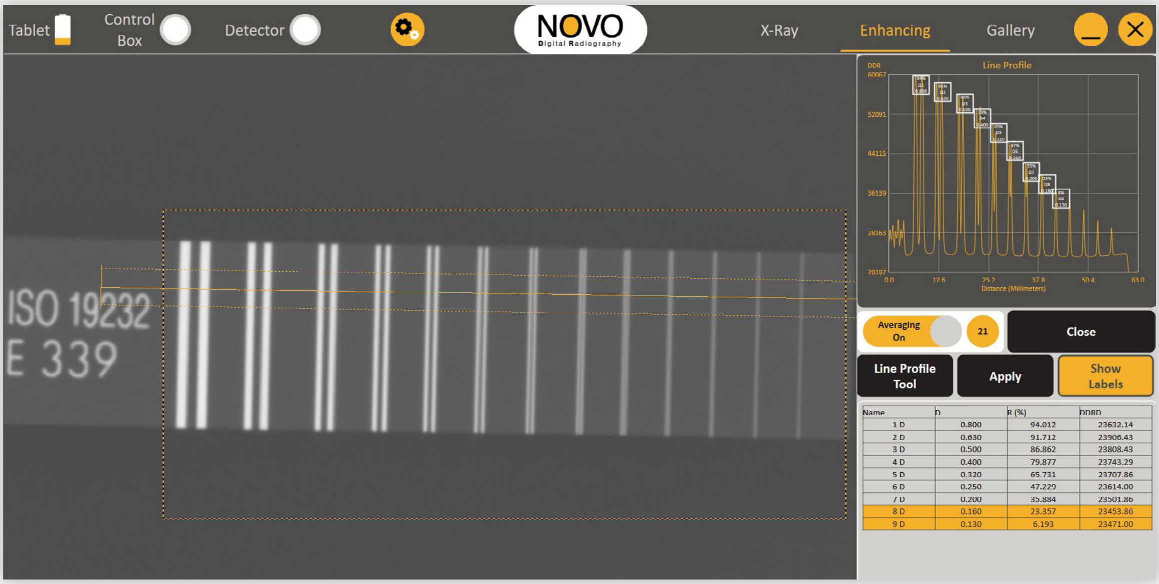
Appendices

What is a Duplex wire IQI?

Duplex wire IQI is used to evaluate and measure the BSR (Basic Spatial Resolution) or total Image Un-sharpness in a Digital image. The IQI consists of 13 tungsten wire pairs housed in rigid plastic. The wires are exactly spaced to correspond to the diameter of each pair. The level of un-sharpness is indicated by the number of wire pairs which can be seen. As un-sharpness increases, the wires merge to form a single image and the spacing cannot be identified. Measurement is not evaluated visually, it is evaluated mathematically using a Line Profile tool. By pulling the Line profile Tool over the wires, a plot is formed of distance vs. grey levels (or DDR).



Normally, a 20% dip is required in order to determine that the wire is “seen”. Then, after determining that the wire is “seen”, we go to a conversion table and “translate” the wire number into an un-sharpness value. This number determines the DDA’s effective resolution.