Optimized Digital Radiography Using Co-60, Ir-192 and Se-75 Sources to Achieve Weld-Quality Images

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ABSTRACT
Radiography using gamma sources has traditionally been carried out using film to achieve weld quality images. Digital radiography offers many advantages over wet film processing – speed, convenience and cost being primary benefits. However, most digital radiography solutions are optimized for X-ray sources, not the gamma sources that are more commonly used in field applications.

This paper describes a cost-effective digital imaging solution which combines the best hardware and software with the experience of an industry-leading gamma source company. This total solution has been extensively evaluated with Co-60, Ir-192 and Se-75 sources in a variety of contact and non-contact NDT applications, using industry standard phosphor plates from several vendors.

Results of the evaluations will be presented, along with recommendations for optimizing performance by selecting the best plates, exposure and scanner settings for each application.

2. System Description

The SENTINEL™Vision system is comprised of three elements: a high-resolution portable scanner (Fig. A), highly effective imaging software, and a computer/display package in a variety of configurations. The elements of this system have been carefully selected to provide extremely high performance, while offering the robust simplicity necessary for demanding on-site inspections.

Fig. A : SENTINEL™Vision HR scanner

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4. Variables

There are many variables associated with image quality in CR applications, and these can broadly be divided into three groups:

Those which are directly under the control of the radiographer, such as exposure time, type of film or Phosphor Storage Plate (PSP), source-to-film Distance (SFD), combinations of lead screens, etc. Following established best practices in setting up the inspection geometry allows the best image quality. Figure B shows a typical inspection geometry for a contact shot on a 6” pipe.

Some are characteristics of the equipment being used, and thus can be controlled by the manufacturer. Examples of these include hardware capabilities such as scanner pixel resolution, laser power and spot size, and software tools such as filters which can be applied to the captured image.

And there are physical characteristics and the laws of physics, which always have to be taken into account. These include the type of source, activity of the source, focal size of the source, the inverse square law and other immutable characteristics of the universe. This category also includes noise-generating Compton Scatter, which must be controlled in order to reduce noise in the final PSP images.

5. Characterization

Since this investigation sought to deliver the best quality possible, the scanner was calibrated with each of the plate types to be used prior to taking and evaluating any images. This was necessary because imaging plates of different types vary in thickness and flexibility, and consequently react slightly differently to the feed mechanism of the scanner. The calibration removes any image distortion caused by the mechanical variations. However, this step only takes about 2 minutes, and only needs to be undertaken once for each plate type, unless the scanner hardware changes.

Digital imaging plates from major manufacturers were used for this investigation. High performance and normal duty plates were included, and also one plate which fell somewhere between the two in performance. Initially the exposure time was calculated to give a dose to the PSP equivalent to D4 or MX125 film, but it quickly became evident that the imaging plates required considerably less dose than conventional film. While the different manufacturers’ plates varied, the optimal dose was generally found to be in the 800mR to 1.2R range.

Applications tested included contact shots on 3” Schedule 40 and 6” XS pipe, stand-off shots on 2” Schedule 80 boiler tube, and various stainless steel plates up to 4” in thickness. In all cases the Source to Film Distance (SFD) was calculated to meet the requirements for geometric unsharpness per ASME Section V. Figure C shows an example of the unsharpness calculation for 3” pipe.

Sources used included Ir-192, Co-60 and $^{75}$Se$^{ntine}^{TM}$ with different activities and diagonal focal sizes, although most of the shots were taken using $^{75}$Se$^{ntine}^{TM}$ and Ir-192 since these isotopes are most commonly used for pipe weld inspections.

Scanner variables were adjusted to gauge their effect on image quality. The pixel resolution ($\mu$m/pixel), photomultiplier voltage (amplification factor), pixel binning, and other factors were adjusted. Exposures from a variety of applications were then scanned and evaluated at each setting.

Images were evaluated by three experienced radiographers using a 5 Megapixel monochrome monitor. Inspection criteria were selected by reference to the ASME Section V standard, using both plaque-type and wire-type penetrators. Where the standard called for the smallest wire of a wire IQI, the next smallest IQI was also placed on the sample to measure the best quality that could be achieved.

Details of each shot were recorded in a spreadsheet, with analysis by consensus and notes added to clarify the image quality achieved. Scanner settings were modified in response to these results, and we were quickly able to determine which made a significant difference, and which had minimal effect.

Once we were confident that we had optimized the scanner settings, we were able to concentrate on investigating which physical source characteristics and radiographic techniques achieved the best image quality in combination with particular isotopes and scanner settings.

6. Results

In general we found it relatively simple to achieve weld-quality images with isotopes using the CR system. In many
cases we were able to exceed the code requirements for wire-type IQI’s and plaque-type penetrometers.

The pixel resolution of the scanner has a significant effect on the ultimate quality of the image, and also affects the scan time of the PSP through the scanner. In fact it is a trade-off - a lower resolution such as 100 µm/pixel gives a faster scan time but a slightly lower-quality image. In areas such as profile radiography this may well yield adequate images which meet all criteria of the governing codes.

However, for the highest quality images, we determined that a 50 µm/pixel resolution provides a good balance between image quality and scan time. Although the scanner is capable of achieving higher resolutions, the increase in image quality is not typically necessary, since the most stringent image quality criteria can easily be met at the resolution suggested above. In addition making the scanner resolution smaller to the point where it exceeds the capability of the imaging plates provides no benefit, since the plate then becomes the limiting factor in image quality. Figure D is a CR image of 2” boiler tubes scanned at 50 µm/pixel. It clearly shows the required #6 wire and 2T sensitivity, as well as visible weld characteristics such as tungsten inclusions and cluster porosities.

Likewise, the gain of the scanner PMT (photomultiplier tube) has a significant effect on both image quality and shot time. Raising the gain of the PMT allow shorter shot times, however the trade-off is an increase in image noise, which can lead to unacceptable results.

Non-scanner variables which affect the image quality include both the plate type used, and the characteristics of the source.

We found that that the lower-performance plates from any manufacturer are not typically adequate for weld-quality imaging. However, both the high performance plates, and the mid-range plate that we tested are certainly able to provide results that meet or exceed the relevant codes. When scanned with optimized scanner settings, we found that a dose of 800mR to 1.2R on the imaging plates delivered acceptable image quality. This compares favorably, for example, with the dose required to achieve a 2.5 density on D4 or MX125 class film. Using CR technology allows the shot time to be reduced by about 50%, improving efficiency and reducing personnel radiation exposure. If shot times are not critical, then a lower intensity source can be used, which can potentially reduce both radiation exposure and the size of any controlled area.

Because of the above, the use of CR technology in combination with SCAR (Small Controlled Area Radiography) techniques and products is a viable approach to minimizing both radiation exposure and controlled area, while providing acceptable image quality in a short amount of time.

An additional benefit of smaller activity sources is their reduced focal size, which contributes to lowering geometrical unsharpness and improving the definition of the image. We found that the diagonal focal size of the source was critical in achieving the image definition necessary to meet the code requirements, particularly for contact shots in the 3” and 6” pipe applications that we tested. It is essential that the source focal size meets the requirement for geometrical unsharpness required by the relevant codes – if it does not, then no amount of tinkering with the shot time or scanner settings will result in acceptable images. Using an advanced isotope such as Ir-192PLUS, which offers a smaller diagonal for a given activity, clearly helps in this regard. Figure E shows a 3” 216 wall pipe contact image shot with a Se-75 source with a .107” focal size. This image clearly shows 3 wires (#6, #5 and #4) on the ASTM A-set wire IQI, and even some of the #3 wire, well in excess of the required #5 ASME V-2 specification.

We also found that $^{75}$Se™ images tended to be smoother and less grainy than those captured using Ir-192. This is most probably due to the softer gamma-ray spectrum of $^{75}$Se™, which has a mean photon energy of 215 KeV vs. the Ir-192 mean photon energy of 357 KeV. However, using 20 mil front lead screens with Ir-192 yielded satisfactory quality images by ASME code standards, comparable to $^{75}$Se™ with 10 mil screens under the same conditions. Figure F illustrates this point.

Although the working range of $^{75}$Se™ is typically limited to about 1 1/8” of steel when used with film, we found it can be used beyond that material thickness range when
used with CR. This is due to the fact that the digital imaging plates require less dose than conventional film, and also the fact that the CR software has tools and filters that effectively increase the latitude of the image and allow hidden details to be brought out. Again though, there is a trade-off - increased shot times and image noise have to be weighed against the convenience of using a single isotope across a broader range of applications. Figure G is a CR image of 3" stainless-clad carbon steel shot with $^{75}$Se$_{\text{SentinelTM}}$, and clearly shows the #12 wire - one wire greater sensitivity than the code requirement.

Cobalt isotopes are also commonly used with thicker materials. Figure H shows a 4" thick stainless steel plate shot with Co-60, and again easily shows the required sensitivity, with the #12 wire and the 2T hole on the 50 plaque penetrantometer both being readily visible.

There are two schools of thought regarding image quality. One approach is to strive for Just Enough Image Quality – images that meet the required standards, but without exceeding them. Exceeding the required image quality can lead to unnecessary additional expense (more expensive imaging plates or longer scanning times, for example), and even to interpretation problems where flaws which are too minor to be problematic are clearly imaged and thus become all too obvious. Thus the concept of “Just Enough image quality” can be used to describe a balance between image quality, and the cost and effort involved in getting to that point.

On the other hand, there is another school of thought known as “Gold Plating the Job”. This rationale involves achieving better-than-required sensitivity, thus ensuring that technicians will turn in shots that meet code, and possibly reduce reshooting. This technique can frequently compensate for the many variables in radiographic set-ups that may produce unsuitable images.

7. Conclusion

Image quality is influenced by a variety of factors. Control of scanner parameters is one major factor essential to achieving weld quality, but cannot compensate for sub-optimal sources or faulty radiographic technique.

The experiments performed by SentinelTM allowed us to optimize these scanner settings for different applications, and they are now accessed through a simple drop-down menu in the SentinelTMVision software. So ease-of-use is maximized for the user, since it is now merely a matter of selecting the isotope, desired quality, etc. from the menu.

To support the scanner’s capabilities it is recommended that the following guidelines be adhered to, in order to achieve the best results:

- Use higher-performance digital imaging plates, rather than lower-performance ones.
- Expose the imaging plates to a dose in the 800mR to 1.2R range.
- Use the smallest diagonal source that is available, such as Ir-192PLUS.
- Pay close attention to calculation of geometrical unsharpness.
- Use $^{75}$Se$_{\text{SentinelTM}}$, rather than Ir-192 where a smoother image is desired.
- When using Ir-192, consider adding 20 mil lead screens on the source side of the imaging plate.

Computed Radiography is capable of producing viable weld-quality images using gamma sources, provided both the scanner settings and the radiographic factors are in harmony with each other. The work we have done, and the solution we provide, allows the user to repeatedly meet industry standards with maximum efficiency.

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