Stationary & Portable Use of a-Si Flat Panels in NDT Industries

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Introduction

Much has been written and discussed over the years about Amorphous Silicon (a-Si) Flat Panel Technology and the revolution that Digital Radiography (DR) is going to play in the modern NDT world; however this paper is not going to emphasize the core a-Si technology, rather point out the adaptations and developments made in order to use this technology in a real world environment. It will try stress applications that are now using this unique radiographic method in order to provide fast, efficient and a high level of imaging in both laboratory and field applications. The eventual goal of this paper is hopefully to enlighten, shake up and change some pre-existing misconceptions as to what can be done with this technology, highlighting sample usages and customers testimonials who have been early adopters of this technique.

Flat panels first started being used in the 1990's mainly for medical applications and entirely in "laboratory" environments. System design and the scintillators chosen made these panels sensitive to temperature and humidity, allowing for operation only to be done through a desktop PC computer utilizing a specialized Frame Grabber in the computer PCI slot. In addition the panels had to have an 110V or 220V AC power supply located within 1.5 meters of the panel itself along with a separate cumbersome data cable which severely limited the distance between the actual panel and the computer controlling it.

These constraints may not have been limiting factors for hospital or even certain industrial usages, however they entirely ruled out the possibility of taking this type of technology into the field for NDT applications, such as field testing of pipes. All this changed in the year 2001, with the introduction of the first truly portable a-Si Flat Panel System called the Flat *f*oX-17, which encompassed all the components needed to operate an X-ray imaging system in one man-portable carrying case. This system, based on existing off-the-shelf flat panel technology using highly reliable Gadolinium Oxide scintillators, is able to withstand the pressures of field use; however, incorporated some major changes and adaptations allowing the equipment to be a truly Portable (or Field Operational) system. The main component that allowed for this revolution was the introduction of an **Imager Control Unit (ICU)** which houses embedded hardware and software, facilitating the following essential elements:

1) 3-5 hours battery operation of the Flat Panel in the field, or an unlimited operation time provided by a vehicle inverter, hence ruling out the need for access to AC

2) A standard laptop used to run the system, without any PCI Frame Grabbers required

3) One lightweight 50m cable handling both power and data running between the imager (or even the usage of a wireless transmitter for up to and over 200m), thus allowing for placement of the imager far from the computer, enabling for true field operation of the system with high powered X-ray sources.

*f*oX Rayzor ICU

Flat *f*oX-17 ICU

Large Format Panel & ICU

This ICU is really the heart of the system controlling all imager communication, allowing us to manipulate and send 14 bit, high resolution images (roughly 15MB of information) with extreme speed and ease (2-5 seconds). This is achieved by the use of proprietary software and hardware performing these unique tasks. Furthermore the ICU houses the rechargeable battery, power supply and charger, thus handles all of the very delicate power management required for the a-Si panels.

Flat *f*oX-17 and *f*oX Rayzor Portable a-Si Inspection Systems Packaged in a Pelican Case

The case housing the components is not just a mule, but rather serves in addition as an operational platform. The inspector can operate the equipment in almost any environment, wherever the X-ray images need to be taken. The case has room to house a unique and very small, lightweight 270kV pulsed Golden X-ray source allowing for strong punching power and relative safe operation (safe back off distance is only about 5-6m). It can literally be set-up in 1-2 minutes, with immediate imaging to follow.

Many accessories have since been designed, including wireless X-ray & Digital Wireless Data modules, tripod mounts and protective covers for the panels. Today this large format imager provides a 28.4cm x 40.6cm imaging area with 14 bit imaging and 4 lp/mm, without using any geometric magnification (much higher resolution can be achieved when using microfocus X-ray sources and magnification).

One of the most interesting developments, has been the introduction of the specially designed *f*oX Rayzor a-Si Flat Panel system (in 2003), which boasts all of the benefits of its

larger *f*lat foX-17 detector. This 13mm thin panel was intentionally designed to be the thinnest digital imager ever produced . The unique panel design enables imaging right down to the bottom and to the side of the imager, thus allowing it to be slid into very difficult access areas. The Rayzor can operate for 5 hours on batteries and uses the same hardware and software as the Flat *f*oX-17, making the imagers fully interchangeable.

Once the concept of working with an ICU had been implemented, much planning and design where put into the proprietary software allowing for true field use of the technology. The software handles all of the imager readout and automatic calibration, controls the X-ray from afar and provides the user with a wide range of enhancing tools and data base capabilities on site. Bear in mind that one of the main benefits of a DR system is that the results are immediate, meaning the operator can see his end result without having to do any development or scanning, and does not have to go back to an office to get his results. Furthermore, if repositioning or image tweaking is required, it can be easily executed on the spot with new positioning or a change in exposure, being clear-cut and known from the previous shot taken.

Some relative industries that are already using Flat Panel technology for both laboratory and field applications are listed below, along with some testimonials:

- **Petrochemical/Piping Industry**
- **Air Force/Aerospace Maintenance and Testing**
- **Ammunition and Ballistic Ceramic Inspection**
- **Cement and Building Inspection**

Petrochemical/Piping Applications
One of the first industries to take a serious look and to adapt this new technology was the Petrochemical/Piping Industry - basically, anyone who has to inspect piping for corrosion, erosion and welding integrity. The speed and ease of being able to setup the system within a minute or two, coupled without having to remove piping insulation; and more importantly, to get real time results in the field, have proven to be a winning combination. A-Si panels are one of the fastest and most sensitive X-ray detectors available and have 10 to 100 times the sensitivity of film previously used. This high sensitivity dramatically decreases the exposure time needed for X-ray shots to mere seconds and can even allow the operator to use a portable 270kV Golden pulsed XRS-3 X-ray source in place of radioactive isotopes for some inspections. Corrosion and erosion are easily identified with the systems, and wall thickness measurement can be made by using line profiling of the pipe walls. Slag inclusion, undercutting, and all types of cracks become easily identifiable either using standard X-ray images, or can be intensified by using Emboss 3D tools.

Open minded service providers who were used to taking limited number of images per day and then having to run back to the lab to develop them, soon found that they could do infinite more cost free shots in the field and receive immediate imaging results. Jobs that once took hours, now could be facilitated in just minutes. Below are a few e-mails of real service providers who took the time to write down what they really thought of this technology in field:

Hello again!
There is one image that shows just how good this new system is. That is the "Leak in a pipe" image. There was a suspicion about a leak in one pipe, but no one couldn't tell for sure where it could be found. No problemo! The great Vidisco Flatfox and a team of two experts (me and my father) rushed to the scene and with just 3 shots we were able to locate the hole! And it all took less 10 minutes! Could it have been done with conventional x-ray equipment...? HARDLY! At least it would have taken hours to do it.

Have a nice weekend!

Best regards,
Toni Kovanen
NDT Servitek Oy
Finland

Another service provider in the United States wrote:

Hi Mike and Scott,

What can one say?

Jesse has had a great week with the system – shut down most of a refinery after being asked if he could try a shot on a 4 valves in a 1"high pressure naptha line (this was in addition to some work we were being paid to do). Nominal wall is .220, he found a 0.010 patch on an exit bend, chief inspector called for crash stop – they love us and hate us at the same time – client is now putting together an RFQ for all of their small bore piping.

Regards,
Mike

Although the panels have been designed to work in the normal X-ray energy levels, even Iridium sources can be used with these panels when applying shielding, mainly to protect the electronics from long term high energy X-ray effects.

Hello Adar,
Yes, it's suprising me about that sensitivity of panel. I'd shoot with Ir-192 whose activity was 4 ci and exposing time was 9 s for process steam tube diameter OD 150 and 6,3 mm wall thickness. The tangent area and drilled test holes showed very well in image!
Other "real work" object was steam cooler in main steam manifold with wall thickness 25 mm, and the wall thicness of the ejector located inside of the manifold was 12 mm. So total wall thickness was 74 mm and shot with 30 ci activity and 50 s exposing time. The details of the inner ejector showed very well!
The shield on electronic area was 8 mm of lead.
I'll going back to the office in next week and I'll send the pictures for you from there because fastest e-mail connection.
Will be back soon

Best regards

Kari

These are just a few examples of experts working in the field who are benefiting from this technology.

Aircraft/Aerospace Industry
The Aircraft/Aerospace industry is another market that can make elaborate use of a-Si flat panels. Both stationary and portable configurations are being used by Israel Aircraft Industries, Aerobus & Boeing component manufactures and many Air Force NDT professionals around the world.

Both the *f*lat FoX-17 and *f*oX Rayzor a-Si flat panels are compliant with the Boeing BSS 7075/7044. Systems can be fully automated to dramatically reduce inspection cycles and translate into great savings.

Manipulator Arm Laboratory Set-up

Automatic Lap Joint Inspection

Below are listed two charts - one showing the comparison between Digital Flat Panel (DR) Imaging vs. Film Imaging. Besides the fact that DR totally eliminates all the handling and expense of chemical, the major imaging benefits over film can be summed up as follows.

DR provides:

1) Faster imaging - image upon request
2) More flexible imaging media - wide dynamic range
3) Ability to perform extreme zooms over the entire image
4) On screen easy annotation
5) Database capabilities - easy archiving, query & search and sharing files with colleagues

The below chart shows a comparison by category:

Digital Flat Panel Imaging vs. Film Imaging

	Film-based System	Flat-foX-17 /foX-Rayzor
Exposure time	Minutes	Seconds
Developing time	8 minutes per film	None - image upon request
Multiple thickness (i.e step wedge)	Number of exposures for multiple thickness	One exposure
Enlarging	Manually, using magnifying glass X10	Automatic zoom up to 800%, no digitizing cubes (improving the ability to see the defect)
Black level density	Fixed, cannot be change	Ability to look at 16,384 grayscale
Defect marking	Manually marked on the film	Software Annotation Tools (visible or hidden) - accurate measurements
Comparing two images	Operator forced to analyze each film separately	Ability to compare up to four images on the screen at the same time & analyze the results
Archive	Need large physical storage room	Digital archive - thousands of images saved on hard disk or other digital media
Searching for image	Manually searching in the archive	Automatic query - immediately receive the image on screen
Sharing information	Sending the film to the customer by mail (risk losing the information)	Sending the digital image by e-mail Safeguarding the original image
Field work	Returning to the lab for film development	Image on site
Repeat exposures	If" bad "image acquired, operator needs to return to the field for another set of exposures	Repeat exposures on site Immediate results

This second chart shows the substantial financial savings achieved by one customer who previously used film for this particular job

Savings by IAI when implanting a-Si Flat Panels versus the same inspection done with X-ray Film

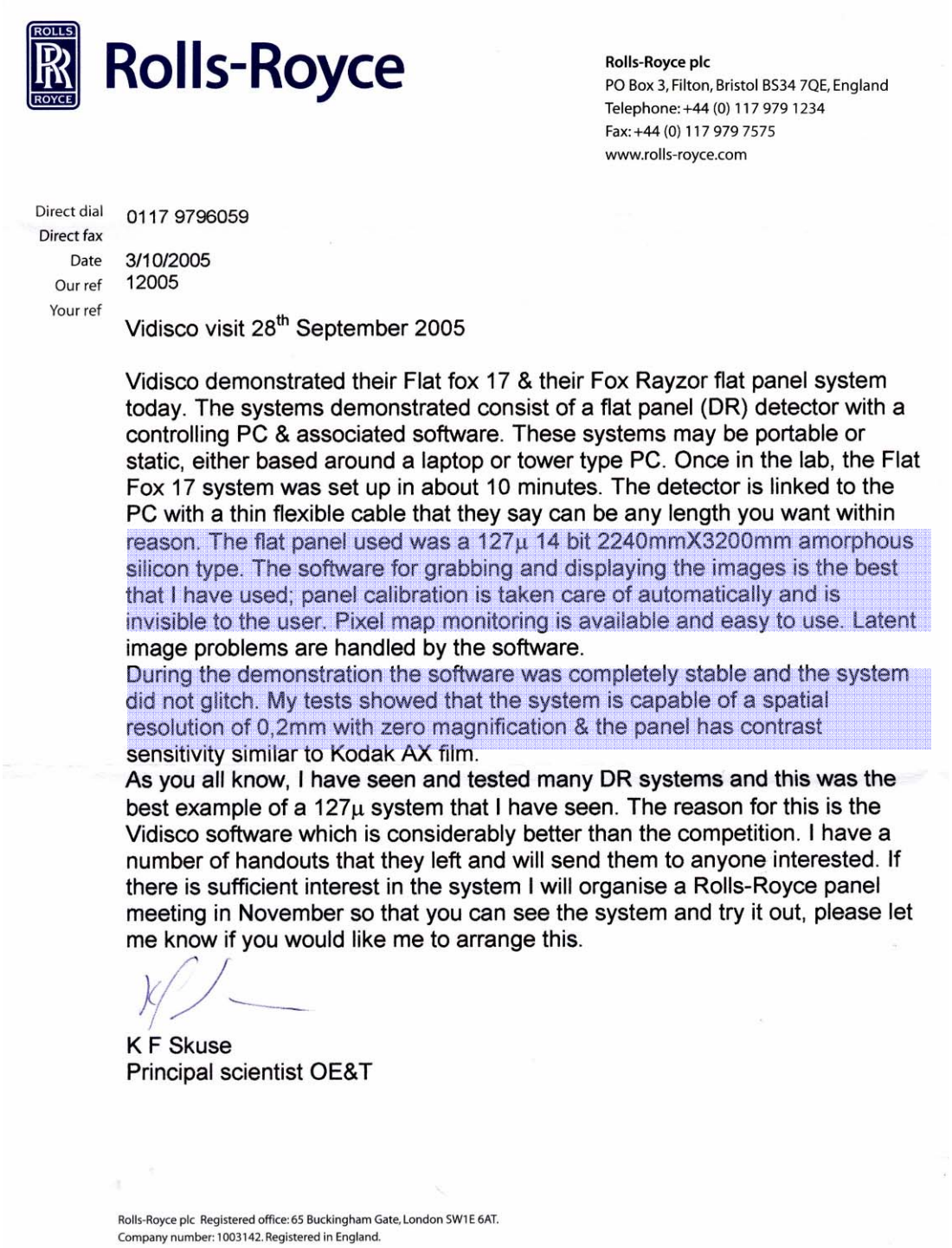
Film Technology			**Digital Flat Panel Technology**		
Procedure	Cost	Annual Price	Procedure	Cost	Annual Price
Photography	$6	$43,500	Photography	$3	$21,750
Development Time	$4.5	$32,625		$0	$0
Film & Chemicals	$2.5	$18,125	CD	$0.03	$217.50
Report Preparation	$3	$21,750	Report Preparation	$3	$21,750
Laboratory	$1	$7,250		$1	$7,250
Maintenance	$1	$7,250	Maintenance	$2.2	$15,950
Storage	$.02	$1,450	System Cost	$0.05	$362.50
Total Annual Cost	$18.02	$131,950		$9.28	$67,280
Total Annual Savings					$64,670

In addition to laboratories, the imagers can also be used in the hangar or even on the tarmac for fast set-up, fast imaging and high quality X-ray images directly on aircraft. Planes and unmanned aircraft can be monitored on a regular basis, with images of critical components detailed and recorded. Imager comparison and analysis is easily performed in the field between previously taken shots and the most recent one, as the built-in database is at the fingertips of the NDT specialist on the laptop computer of the system.

F-15 Inspection

F-111 Inspection

When presenting this technology to Rolls-Royce, at first they were skeptical at what could be achieved with such a system. The below letter speaks for itself in showing the type of impression gained after working with this equipment and realizing what a true revolution this type of hardware and software approach entail.



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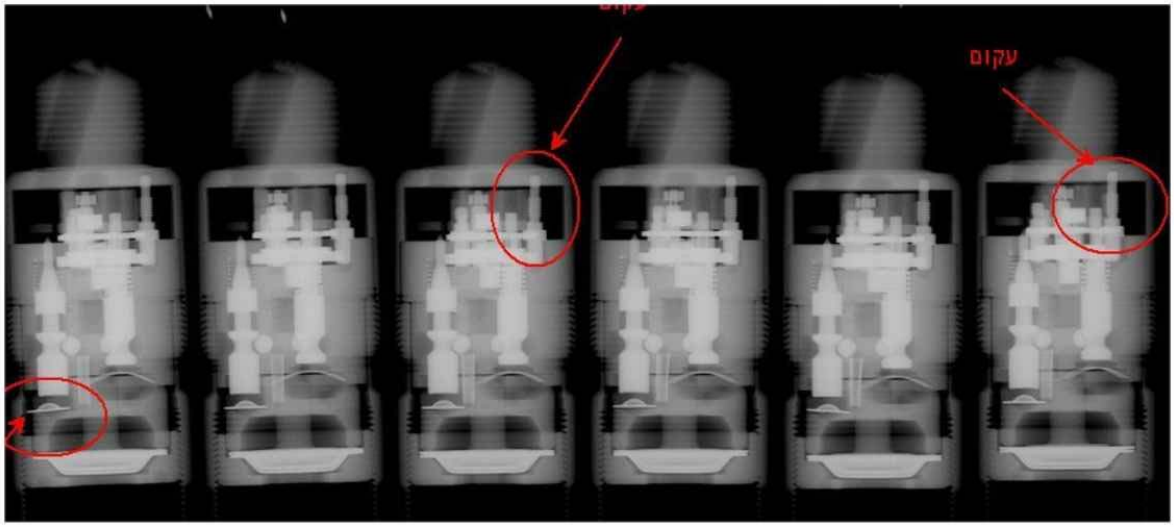
Vidisco visit 28th September 2005

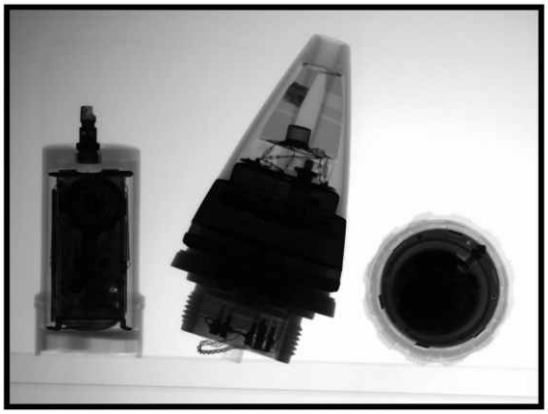
Vidisco demonstrated their Flat fox 17 & their Fox Rayzor flat panel system today. The systems demonstrated consist of a flat panel (DR) detector with a controlling PC & associated software. These systems may be portable or static, either based around a laptop or tower type PC. Once in the lab, the Flat Fox 17 system was set up in about 10 minutes. The detector is linked to the PC with a thin flexible cable that they say can be any length you want within reason. The flat panel used was a 127μ 14 bit 2240mmX3200mm amorphous silicon type. The software for grabbing and displaying the images is the best that I have used; panel calibration is taken care of automatically and is invisible to the user. Pixel map monitoring is available and easy to use. Latent image problems are handled by the software.
During the demonstration the software was completely stable and the system did not glitch. My tests showed that the system is capable of a spatial resolution of 0,2mm with zero magnification & the panel has contrast sensitivity similar to Kodak AX film.
As you all know, I have seen and tested many DR systems and this was the best example of a 127μ system that I have seen. The reason for this is the Vidisco software which is considerably better than the competition. I have a number of handouts that they left and will send them to anyone interested. If there is sufficient interest in the system I will organise a Rolls-Royce panel meeting in November so that you can see the system and try it out, please let me know if you would like me to arrange this.

K F Skuse
Principal scientist OE&T

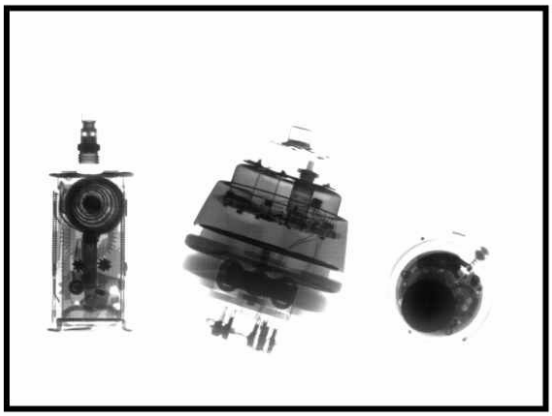
Ammunition Inspection

Ordnance of all forms and sizes need to be checked both at the production stage and also during its lifetime to ensure that fuses and high explosives remain in the desired state that is required to safely transport, store and fire these devices. Some ordnance have 100% inspection requirements, while others require only sample testing. Whichever is the case, a system that can be brought to the munitions, and not the opposite, provides some clear cut advantages over having to move potentially dangerous items and meeting required regulations. The operator can take just one shot to look at different materials - both high and low absorbent items - due to the very wide dynamic range provided by this technology and use of Window Leveling tools to look at the relevant gray scales. It goes without saying, that these systems are fielded today in over 65 countries around the world for identification of IED's (improvised explosive devices) and EOD (explosive ordnance disposal) applications, where the time factor is even more critical than most NDT applications.





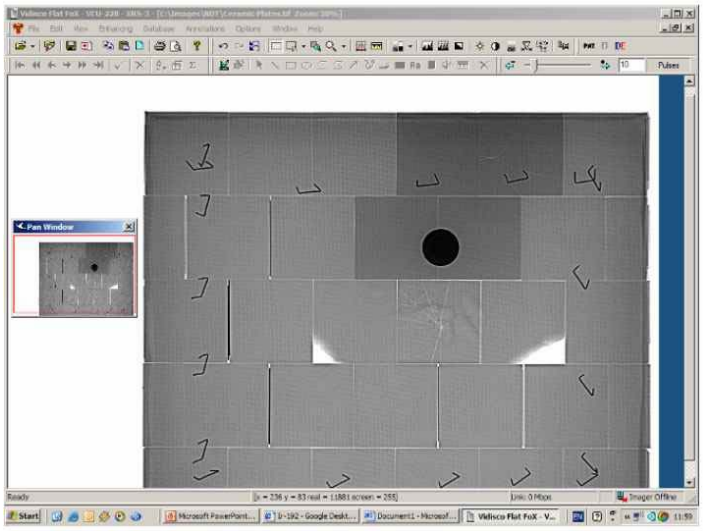
X-Ray Image before Window Leveling



X-Ray Image after Window Leveling

In a related field, a-Si Flat Panel technology lends itself very well to the inspection of ceramic ballistic plates that need to be checked both at the production stage, and also from

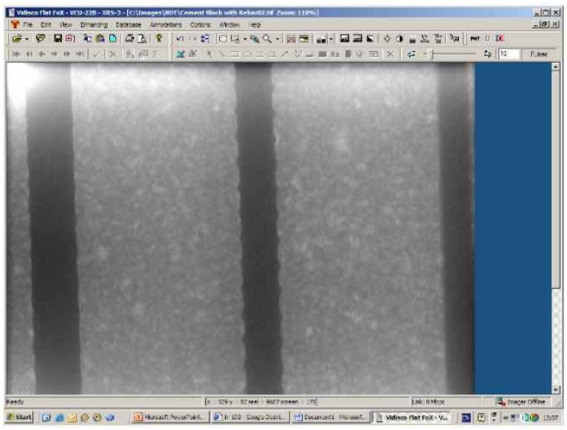
time to time in the field. Below is a image taken of a ballistic plate used for armored vests, and a short excerpt from inspectors who used this technology for the first time:



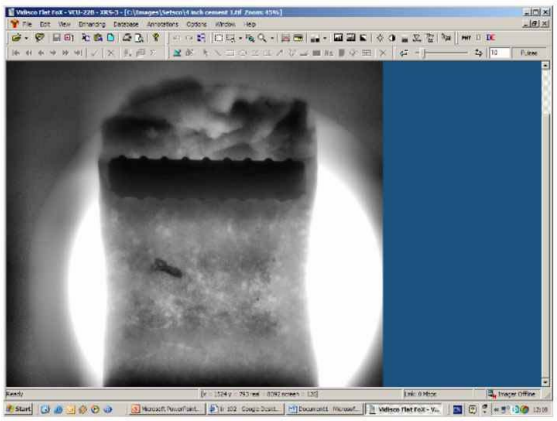
The work at Yuma went very well last week: they planned on two days to evaluate the plates and they finished in three hours! Larry is off with them this week to Panama to test the plates stored in jungle environment. The following test will be in Alaska.

Building Industry - Cement Core and Rebar Inspection

The last example of real day usage that I want to present here is the inspection of rebar and cement core primarily in the building industry. Once again due to a-Si high sensitivity and excellent dynamic range, these systems can be used in the field to take X-ray images without having to do some of the "destructive" work that has been done in the past, and can give immediate results without having to take samples back to the laboratory. Below are two images, one of 6" of cement wall taken with a conventional Zeifert CP source set at 160kV, while the other, a 4" concrete core taken with a Golden 270kV pulsed X-ray source. Note that with both sources, the operator received the required information needed:



6" Cement Wall Taken with Zeifert CP Source – 160kV



4" Cement Core Taken with Golden 270 kV Pulsed Source

Summary

It has become quite obvious that the former technological constraints of taking a-Si Flat Panels into the field have long been eliminated, and that a wide range of NDT activities can be performed with this technology. Flat Panel technology is proven and mature, providing the fastest imaging and highest quality shots. There are no hidden costs after the initial investment, and basically an unlimited amount of images can be taken with the system. The many applications that have a high number of images required, will experience a return on investment in under one year, if not in just months. Flat panel systems are currently being used around the world for a wide range of activities, and the petrochemical, aerospace, ammunition, casting & welding and the building industries are only just a few examples of NDT applications utilizing this exciting technology. Never before has the NDT professional been able to carry into the field a complete data base and imaging system where immediate image comparison and analysis is possible. Today's NDT operators can finally enjoy the super high dynamic range and excellent resolution images provided by a-Si Flat Panel Systems in a real time format in the field - this translates to less time required for the inspection coupled with an overall savings in expense.