

Going Digital: Assessing the Viability of Computed Radiography

Innovative Method for Non-Destructive Testing Has Strengths & Limitations

MANY NAVAL ACTIVITIES

including the Navy's Fleet Readiness Centers (FRC) are faced with replacing aging chemical and film-based radiographic imaging systems used for non-destructive testing (NDT) (or non-destructive inspection (NDI)) with systems that do not rely on such an approach—so called computed radiography (CR) systems. However there are benefits, requirements, concerns, and challenges associated with implementing this technology that are worth noting.

Computed & Direct Digital Radiography. What's the Difference?" for a summary of three radiography inspection technologies). A CR system's four main elements are:

1. A phosphor image plate (IP)
2. An IP reader
3. A central processing station with special software
4. A high-resolution monochrome X-ray monitor

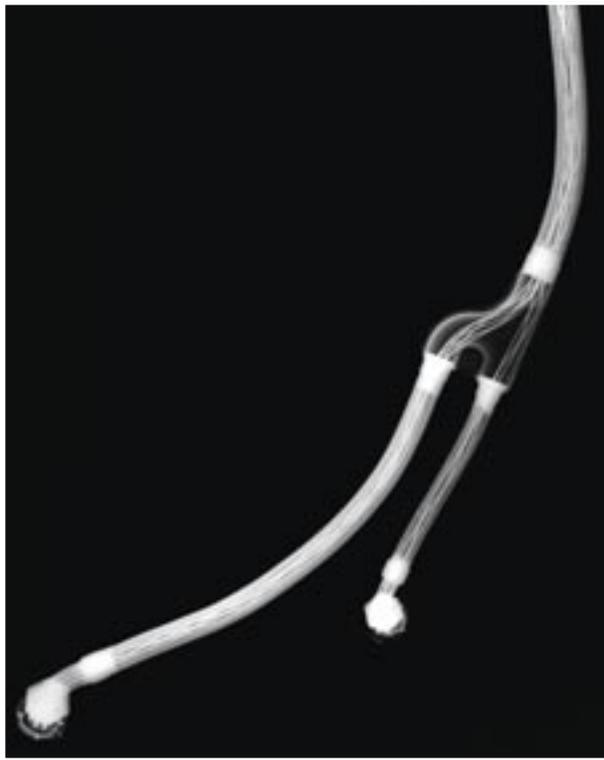
A computed radiography system includes all the elements needed to create an X-ray image of a part under inspection.

Computed Radiography System Basics

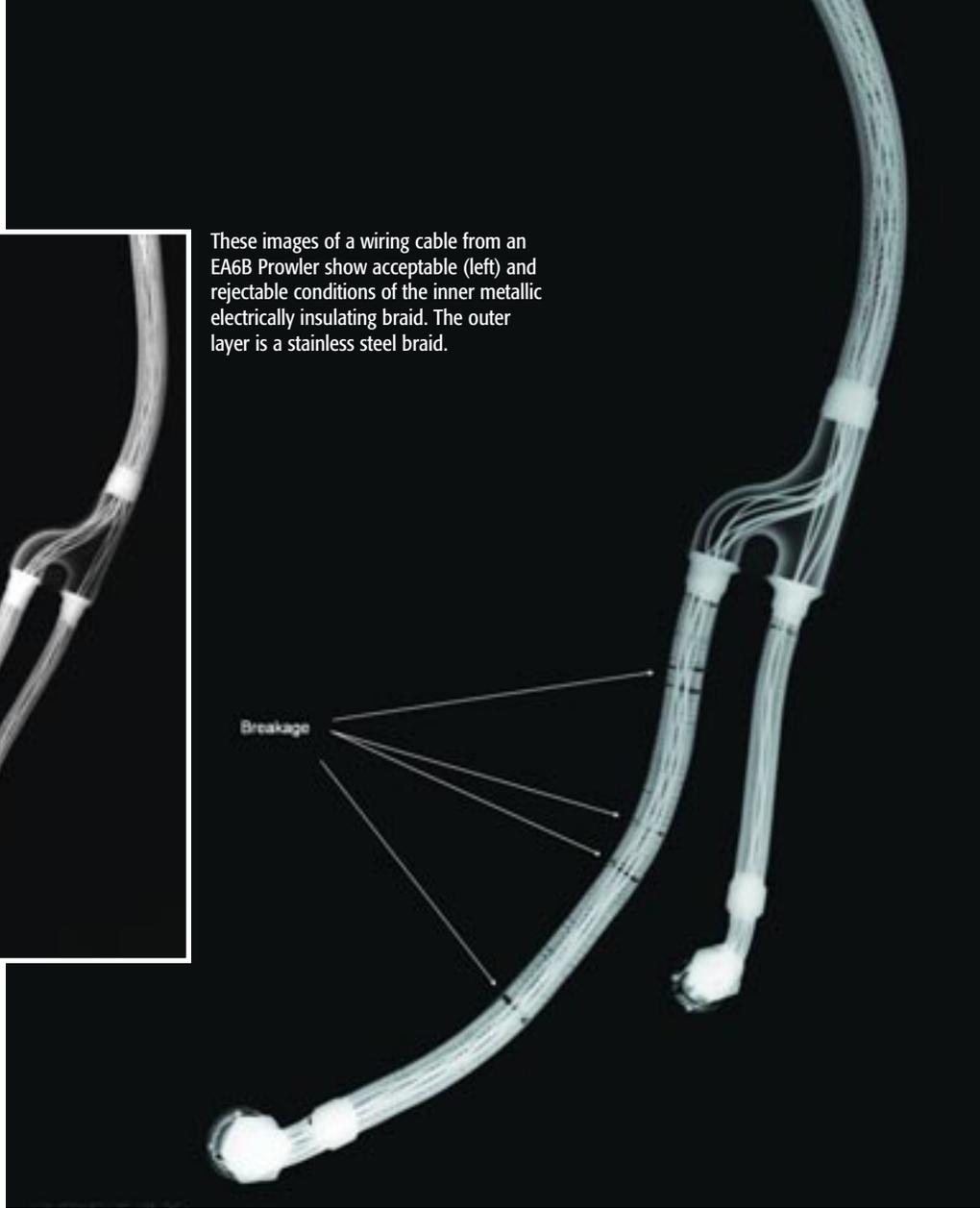
A CR system, a type of digital radiography, includes all the elements needed to create an X-ray image of a component (part) under inspection. Unlike a film-based system, however, the end result is a digital image. (See our sidebar entitled "Film-based,

The plate surface is coated with storage phosphors that capture the energy from radiation. These phosphors absorb and store the radiation energy and create a latent image. The exposed plate is processed when a laser in the IP reader scans the plate and the stimulated phosphors reveal the image as visible light. The visible light can then be converted into an





These images of a wiring cable from an EA6B Prowler show acceptable (left) and rejectable conditions of the inner metallic electrically insulating braid. The outer layer is a stainless steel braid.



phor material and exposure. The plates may be reused numerous times. Similar to conventional X-ray film, phosphor plates are stored in cassette format.

CR has only recently been optimized for industrial purposes. The latest generation of industrial CR system is durable and robust and has greatly improved resolution and contrast capability. As a result, CR rivals the performance of film radiography in most applications.

Why the Move Away from Film?

Several factors are influencing the move away from film-based X-ray techniques and toward CR systems. They include:

- Eliminating costly chemicals and resulting hazardous waste
- Providing an adaptable image medium

- Reducing other consumables that a film-based system requires
- Protecting worker health and safety
- Improving productivity by reducing work turn-around time
- Allowing for the quick sharing of the results with off-site experts

Eliminating Chemicals and Hazardous Materials

With CR systems, images are generated on a medium that does not require traditional film's chemical bath processing. Traditional film chemicals must be used within a limited timeframe, requiring

processing laboratories to maintain a constant stock of fresh film and chemicals which are rapidly increasing in cost. The cost of procuring and maintaining these supplies is high, and film developing chemicals must be disposed of as hazardous waste, with increasing costs.

Adaptable Image Medium

CR's image plate is typically only .025 inches thick and can be easily cut with scissors or a knife. Image plates can be shaped to meet specific imaging needs, although the cut portion must be refit into the larger IP for reading the image.

Film-based, Computed & Direct Digital Radiography: What's the Difference?

RADIOGRAPHY IS AN NDT technique used to look inside components to ensure those components are free of dangerous defects. X-rays or gamma rays are projected through the component onto an imaging medium. Traditionally, that imaging medium was film. NDT applications are now moving toward digital imaging, much like individuals have moved to digital cameras, and dentists and doctors to digital X-rays. Some of the differences among the technologies are noted below:

TYPE	DESCRIPTION
Film-based	X-ray sensitive film is exposed to radiation source. After exposure, the film holds a latent image (i.e., not visible) until it is developed in a chemical bath to reveal the image of the component.
Computed Radiography	Instead of film, a plate with photo-sensitive storage phosphors is exposed. When the phosphors are stimulated by radiation, they hold a latent image, much like film. Instead of a chemical bath to develop the image, a laser scans the plate and the stimulated phosphors reveal the image as visible light. The light is converted into a digital format and the image is computed. The phosphor plates are flexible and can be cut to different shapes.
Direct Digital Radiography	The X-ray image is captured directly on a rigid imaging plate, which typically is made of either amorphous silicon or amorphous selenium. The image is transferred directly to a computer as a digital file. No intermediate processing step is needed.

Reducing Consumables and Laboratory Equipment

The image plate used in CR can be reused from 200 to 5,000 times, unlike traditional X-ray film. Other consumables eliminated through the process change include envelopes, marking pencils, cleaning materials, gloves, and shields. CR systems also eliminate several pieces of support equipment, including water chillers, safe lights, silver recovery units, light-tight doors or light traps, film viewers, and densitometers for checking film density and

proper exposure, in addition to the developing tanks and processors.

Worker Health and Safety

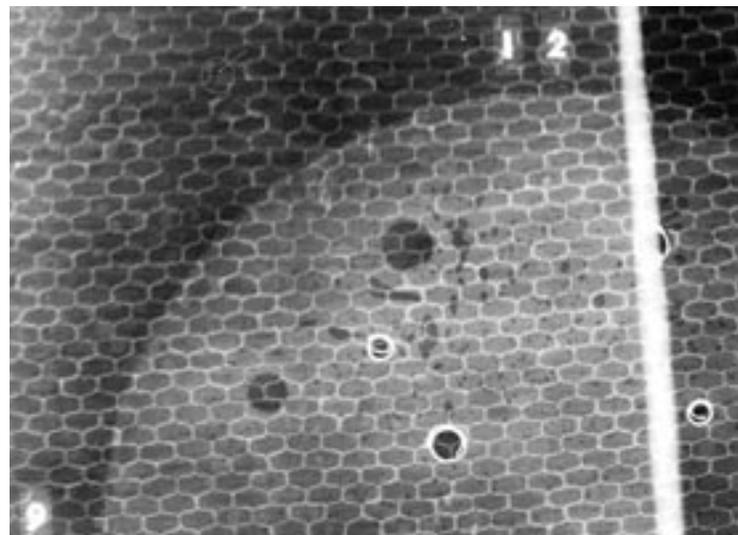
Operators benefit from significantly reduced chemical and radiation exposure. The ALARA concept ("As Low As Reasonably Achievable") is used within the Navy to control radiation exposure. In order to comply with ALARA, an operator

must use some combination of time, distance, and shielding to minimize exposure. In the case of CR, both the amount of radiation and the length of exposure are significantly reduced compared to film, which makes the operator's task safer and faster.

Productivity Improvements

The opportunities for productivity improvements are substantial. First, the reduced radiation dose for exposure and shorter exposure times per shot allow CR inspections to occur within a smaller shielded area. This contributes to quicker inspection site set-up and allows other work efforts to continue nearby. The decreased exposure times also make the inspection process shorter, reducing personnel time. Second, image processing times are down from a minimum of 12 minutes for film to one minute for CR. This enables the system operator to determine quickly if shots are acceptable or need to be retaken. Third, with CR, an operator can manipulate the presentation density and inspect a wider range of material thicknesses with a single exposure on a single imaging plate as opposed to taking multiple film shots that use either

This F18 main landing gear door image illustrates the contrast sensitivity of the new CR system. The door has a carbon/epoxy skin bonded to structural aluminum honeycomb and a repair patch has been applied (circular area). The irregular, dark spots are voids in the adhesive between the patch and the honeycomb. The small, round, dark areas are "unbonds" where the loop of wire was placed between patch and honeycomb to prevent adhesive from penetrating into these areas.



different exposure times or different film speeds. Finally, CR systems allow users to transmit, evaluate, and store images electronically. The digital format makes internet transmission possible, as well as reducing the storage demands of traditional film.

An additional consideration is the future availability of film. As conventional film becomes less prevalent in the consumer world, it is projected that industrial access to conventional film will become more limited as well.

Limitations of Computed Radiography

While CR offers several operational advantages over conventional film processing, it also has its limitations. As with any new technology, it has both a learning and an acceptance curve. Standards for accepting and rejecting inspection results are being developed. Although many ongoing expenses are reduced compared to film, some still exist and the up-front costs to procure the equipment are substantial. Finally, the complexity of CR systems warrants careful consideration by potential installation locations.

The Learning Curve

Conventional film-based radiography has well-established procedures for radiographic techniques. These procedures include the amount of radiation, length of exposure, and resulting image quality. Because CR typically requires less radiation and shorter exposure time, operators need to learn a new process for achieving acceptable results. In addition, the image's spatial resolution (i.e., how coarse or fine the image) affects interpretation of the results. There is concern that until training and standards are well established and coordinated, images potentially could be over analyzed and

anomalies that would have been acceptable under wet film processing will now be rejected.

Standards for Accepting or Rejecting Results

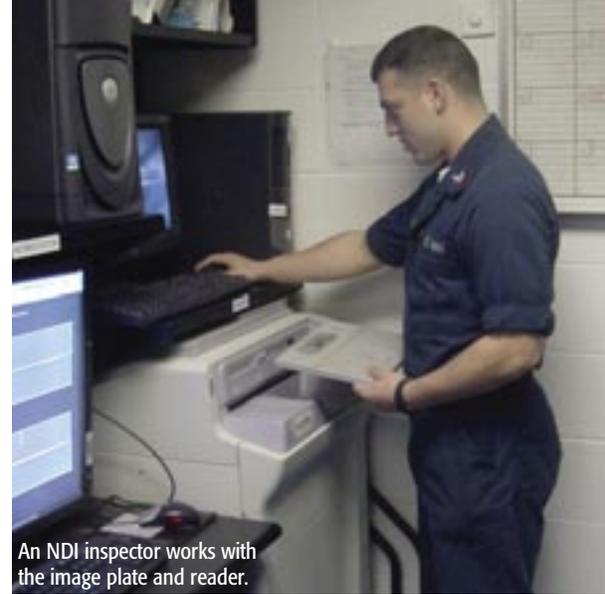
Current accept/reject standards are based on film and the proven history of how defects will appear in a film-based system. Changing the capabilities of the imaging system also changes the predictability of results. Research is needed to build a new stock of digital results, with proper resolution and clarity that are subjected to an analytical process that addresses probability of detection, probability of failure, and desired or expected service life. This process is still underway. Pending new standards, CR will not be accepted for certain types of inspections.

System Expenses

Typical CR systems are more expensive to purchase than film processing systems—coming in at approximately twice the cost. In general, depending upon system configuration, conventional CR systems approach a purchase cost of \$125,000 to \$175,000. It is important to note that these costs are dropping while the cost of the film-based system is staying the same or increasing. Each CR image plate costs approximately \$550 to \$700, nearly equal the cost for 100 sheets of film. An important difference, however, is that the CR image plates can be reused up to thousands of times.

The image plates require occasional cleaning and other maintenance. While climate control for the image plate storage is not necessary per se, moisture can be a serious problem. Moisture and the presence of dirt and grime will shorten the life of the image plate.

Two support equipment items that will still be needed in a CR system are



An NDI inspector works with the image plate and reader.

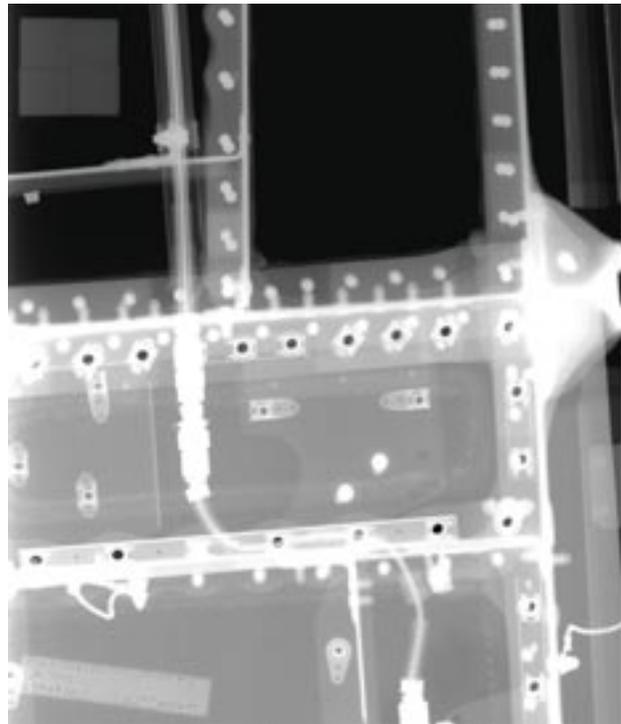
film identification units and some type of storage cabinets for CD-ROMs—items that must be included in the initial purchase of a CR equipment package from the manufacturer.

System Location Requirements

The complexity of CR systems warrants careful attention to the intended installation location prior to implementation. The temperature should be stable, and there should be no heat sources (including direct sunlight) within close proximity. Moisture, excessive dust and corrosive gases will also degrade performance; humidity and ventilation need to be considered and constant vibration and shock must be avoided as well.

Computed Radiography Systems under the Pollution Prevention Equipment Program

The Navy's Pollution Prevention Equipment Program (PPEP) made it possible to procure multiple CR systems for several sites within a single Navy region. Of the systems provided under PPEP, Navy Region Northwest (NRNW) has implementation experience that is key to CR implementation Navy-wide. The first two sites within NRNW—Naval Base Kitsap Bangor and Naval Air Station Whidbey Island—received their systems in 2003 and have used them

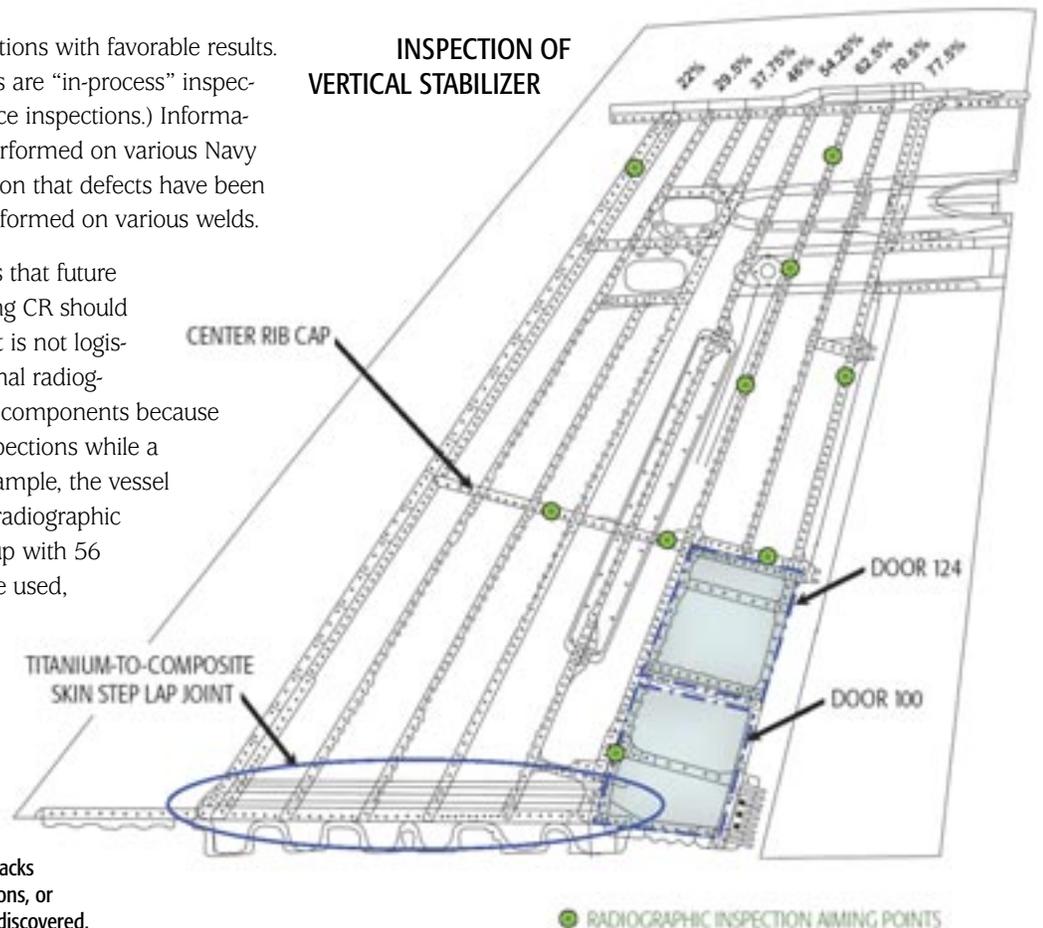


for several informational inspections with favorable results. (Note: Informational inspections are “in-process” inspections rather than final acceptance inspections.) Informational inspections have been performed on various Navy Fleet components and verification that defects have been properly removed has been performed on various welds.

Initial work experience suggests that future time and cost savings from using CR should be substantial. In many cases, it is not logistically feasible to use conventional radiography methods to inspect Fleet components because of the time required for the inspections while a vessel is in dry dock. In one example, the vessel components required multiple radiographic inspections, ultimately ending up with 56 images being taken. If film were used, each image would require 23-minutes exposure time for a total of more than 21 hours—

This illustration identifies the specified locations for film placement for X-ray inspection of the F18 Vertical Stabilizer. The inspection is intended to identify cracks that form in the spars between inspections, or monitor cracks that have already been discovered.

INSPECTION OF VERTICAL STABILIZER



and this does not account for the additional time required for retakes. Protecting workers and ensuring compliance with ALARA regulations would also extend overall inspection time. Using CR for these inspections reduced exposure time to 3.5 minutes per exposure, saving roughly 18 hours in exposure time (retakes, if needed, would only add minutes to this total). And because radiation exposure is substantially lower, ALARA compliance is not an issue.

Given the available vessel time for the inspections, this number of conventional radiographic shots for each of these components would not have been possible.

By performing both a film-based and a CR exposure on the same component, operators demonstrated that the digital images were of the same or better image quality. In addition to comparable image quality, operators welcomed the safety benefits associated with the CR process including:

1. Reducing the exposure to radiation
2. Eliminating the need for film-development chemicals
3. No longer needing to dispose of hazardous waste products



NESDI Project to Validate Use of Computed Radiography at the Navy's FRCs

THE NAVY ENVIRONMENTAL Sustainability Development to Integration (NESDI) program has just launched a new project (#474) entitled "Replacement of Film Radiography with Computed Radiography" to determine the viability of replacing film radiography systems with CR systems at all three Navy FRCs. The demonstration site will be the Fleet Readiness Center Southeast (FRCSE) in Jacksonville, Florida.



FRCSE disposes approximately 120 gallons of hazardous waste produced from film-based radiography operations each year. Film development processes require the use of hazardous materials including potassium sulfite, hydroquinone, ammonium thiosulfate, and sodium sulfate. These materials require special disposal methods which can be costly to the FRC and the environment. To ensure environmental and mission sustainability, steps are currently underway to phase out film-based radiography and implement computed radiography at FRCSE, other FRCs, and elsewhere in the fleet.

A technical evaluation of the VMI 5100MS CR system was completed in Fiscal Year (FY) 2011 and Fleet authorization was given in the first quarter of FY 2012. (Note: See "Authorization of VMI 5100MS Computed Radiography System for Crack Detection and General Radiography" memo dated 11 January 2012.) This technical evaluation was funded by the Naval Air Systems Command's Program Manager-Air 260 (Common Support Equipment). Fleet sites began receiving VMI 5100MS systems in December 2011. The NESDI effort will be dedicated to the additional validation that is necessary beyond the Fleet technical evaluation to ensure that the new technology can meet the FRC performance requirements as well.

Although the performance has been characterized for the VMI 5100MS CR system, FRCSE requirements for radiography must be tested and if possible, converted, to prove that CR is an acceptable alternative to film radiography for FRC operations. The first year of this two year effort will involve obtaining the most recent software and hardware configurations of the VMI 5100MS. Testing of all current film radiographic procedures would proceed thereafter. Testing involves ensuring CR can meet the inspection requirements for film. All standards and components for demonstrating CR would be either fabricated or obtained. The second year would involve finishing technique conversion, completing work on any technical documentation, and getting authorization to utilize CR in the FRCs.

For more insights into the execution of this project, contact Ian Hawkins. For more information about the NESDI program, visit www.nesdi.navy.mil or contact Leslie Karr, the NESDI program manager at 805-982-1618 or leslie.karr@navy.mil.

Projected Savings

Informational inspections using CR have already yielded time and cost savings. Annual savings for a trial CR system have been calculated to be anywhere between \$50,000 and \$194,000, depending on equipment usage rates, specific technical applications, and increasing material and waste disposal costs.

Savings are based upon several factors, including:

- A 500- to 2000-exposure lifespan for the image plate
- Elimination of hazardous waste disposal expenses and the associated cost for silver reclamation
- Saving water by eliminating film rinsing and eliminating climate controls for chemicals
- Reduced personnel cost due to reduced exposure times.

Once the CR process is approved, NRNW will benefit once the CR technology is routinely applied across the region. There are also several expected environmental benefits to

be gained from implementing a CR system. Eliminating chemicals from traditional film development will help meet the waste reduction requirements under the Resource Conservation and Recovery Act and Executive Order 13148 (Greening the Government Through Leadership in Environmental Management). In addition, digital imaging will help reduce reporting requirements. Average annual savings for the newest CR system are projected to be up to \$689,000 based on a general return on investment analysis.

With continued effort and research, Fleet activities will be at the forefront for implementing this new technology for inspecting welds and castings.

Obstacles to Implementation

Regrettably, the Navy facilities that received the CR systems are not yet able to fully utilize them. For these activities, the use of CR is restricted to informational inspections—not final acceptance inspections. Several factors contribute to this limitation. The first factor is the

Perspective from the Fleet Readiness Center Southwest

PERSONNEL FROM THE Fleet Readiness Center Southwest (FRCSW) in San Diego, California (North Island) also have extensive experience with the selection, implementation, and trouble shooting of CR systems. At FRCSW, the types of components on which CR is typically used include:

1. F18 Vertical Stabilizer (internal) spars
2. F18 Inner Wing Panel (internal) spars
3. H53 Tail Pylon Assembly
4. F18 Horizontal Stabilizer Hydraulic Servocylinder internal assembly
5. Parachute Harness Sensing Release unit
6. Control Rods

The first three inspections are intended to identify and monitor indications of struc-

tural cracks in the spars, ribs, or intercostals of structural assemblies. The fourth and fifth inspections are intended to verify proper assembly/configuration of subcomponents internal to major system components. The last inspection included in the list above is intended to identify entrapped water and corrosion of internal surfaces of the control rod tube.

Based on these inspections, North Island personnel have documented the following lessons learned with regard to the proper use of CR:

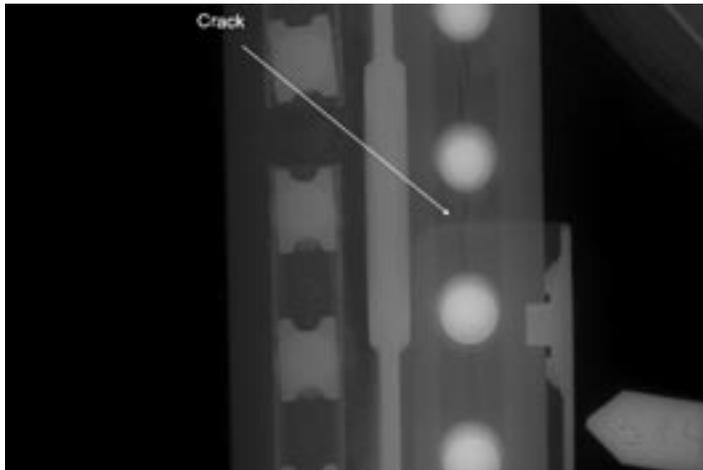
1. It will be necessary to correlate CR with film when detection of “tight” cracks is required. Crack indications in CR can be more subtle than those in film.
2. Application and resolution of Image Quality Indicators that can simulate

“tight” cracks will provide greater confidence in CR when duplicate film exposures cannot be produced.

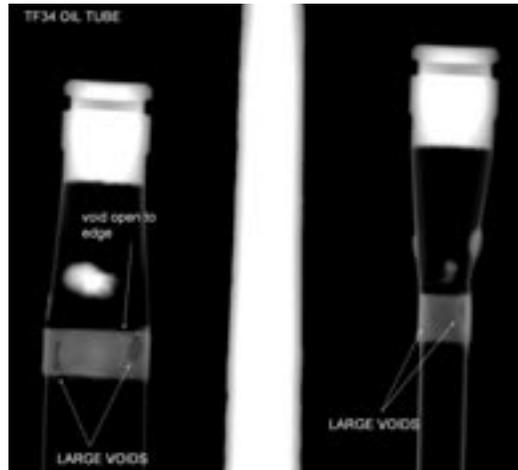
3. Consultation between geographically disparate NDI activities (including the Navy’s three FRCs as well as Marine Air Logistics Squadrons/Aviation Intermediate Maintenance Departments) is simplified by the ability to exchange digital image files.
4. The performance of the CR system’s X-ray Tube Head has a significant impact on detection of fine/low contrast indications.

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The result of a high flight hour x-ray inspection for F18 A-D models taken with wing fully assembled. The top and bottom wing skins constitute about one inch graphite/epoxy composite. The lower flange of the wing spar is about 0.25-inch aluminum. The spars constitute the majority of the load bearing structure of the wing thus the significance of this inspection. The wing is otherwise comprised of fuel and foam. The results image shows span-wise cracks running from hole to hole indicating stress corrosion cracking.



Often radiographic inspections are requested to assess the integrity of a weld or brazed joint. A common defect of these types of joints is porosity or voids. In these images, the darker, circular areas in the brazed section indicate porosity, which is usually the result of a poor brazing process. Whether or not the porosity is allowable is determined by the acceptance criteria from a drawing or welding specification.

reliability of weld defect indications. Because of the major technical differences between the two techniques, discontinuities and anomalies may be difficult for the untrained eye to detect. The capacity to certify that individual components are capable of providing a baseline of information is crucial, but has yet to be established. Related to this is the frequency of certification and calibration. Procedures for system certification (including the frequency of calibration) have yet to be finalized.

Several ongoing studies are being undertaken which will ultimately determine the requirements and procedures for CR inspections. One study is focused on ensuring that the results obtained through CR are compatible with those obtained through traditional film processing. The Naval Sea Systems Command has contracted Northrop Grumman to evaluate the qualification requirements for CR systems. (Note: This is

an ongoing effort and results have yet to be finalized.) The existing operating practices for technicians are for film-based radiography and are not directly applicable to CR because of the major technical differences between the two techniques. The goal is to have a set of procedures that ensure reliable and consistent detection and evaluation results, regardless of the operator. Another study is focused on ensuring that original data in the digital image files cannot be altered.

A third study, sponsored by the Navy Environmental Sustainability Development to Integration (NESDI) program is verifying that a CR system can meet the performance requirements at the Navy's three FRCs. (For more information about this study, see our sidebar entitled "NESDI Project to Validate Use of Computed Radiography at the Navy's FRCs.")

In addition to Navy authorization, these naval activities face their own obstacles to implementing and using CR. Consoli-

dation of inspection processes among the activities is the primary obstacle. In addition, once a determination is made on the lead activity for implementing CR, training the two sites will benefit from standardization.

Summary

CR offers several advantages over film-based techniques, but issues about implementation remain. ↴

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