COMPARISON OF IMAGING CAPABILITIES BETWEEN ULTRASONICS AND RADIOGRAPHY

Draft Final Report
SwRI® Project 14.07558

Prepared for

U.S. Environmental Protection Agency
Mail Code 6608J
1200 Pennsylvania Avenue, N.W.
Washington, D.C. 20460

Prepared by

Department of Sensor Systems and NDE Technology
Division of Applied Physics
Southwest Research Institute®
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May 2004

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1.0 INTRODUCTION

1.1 Background

The overall objectives of the Environmental Protection Agency (EPA) Clean Materials Program are to (1) minimize incidences of radioactive sources that fall out of regulatory control, (2) reduce the potential for harmful radiation exposure to the general public, and (3) reduce possible financial impact to the steel recycling industry. Radioactive-sealed sources, although very useful in many applications, are usually very small in size and, therefore, have the potential to become lost, stolen, or abandoned, and then enter into the public environment. Once they are in the public environment, these sources can inadvertently end up as scrap metal to be melted for recycled metal or end up in landfills. In either of these cases, the sources become part of the general environment, providing the potential to expose the public to harmful radiation. In addition to the public health risk, the financial impact associated with decontamination of industrial facilities and consumer metal supplies is substantial once the contamination has been discovered.

Sealed radioactive sources are contained in many industrial devices and consumer products, such as radiography cameras, industrial and domestic smoke detectors, gauging devices used in manufacturing facilities, and food irradiation systems. The radioactive component of these devices and products is typically sealed in a metal case, which is surrounded by a metal housing in the presence of electronic components and other potentially hazardous materials. Although labels indicating the presence of radioactive material are required by regulation, they often become worn and unrecognizable. The result is that once out of regulatory control, these devices are often perceived as innocuous by industry and the general public and are frequently mistaken as scrap metal.

The EPA Radiation Protection Division's Clean Materials Program is dedicated to minimizing harmful exposures from lost radioactive sources. One approach of interest to the EPA is to provide front-end solutions such as alternative non-nuclear technology substitutes. An example of this approach would be to facilitate the substitution of non-nuclear alternatives that are technologically sound and economically advantageous.

Radiation exposure is a concern because radiation can damage cells. Natural sources of radiation (such as cosmic rays and other sources from outside the Earth's atmosphere) provide approximately 80 mrem/yr. Medical and dental x-rays provide about 90mrem/yr and other exposures amount to another 20-30 mrem/yr. The National Committee for Radiation Protection (NCRP) estimates that the average American receives approximately 200-mrem/yr exposure. The amount of radiation that can cause significant damage differs for various tissues and organs of the body, and depends heavily on the reproductive capacity of the cells that compose the organ or tissue type as illustrated in Table 1.

Table 1. Human Organ Radiosensitivity[1]

Tissue and Organ Type	Sensitivity and Damage Response to Radiation Exposure
Lymphocytes (white blood cells)	Most sensitive
Granulocytes (white blood cells formed in the bone marrow)	Very highly sensitive
Basal cells (originators of complex specialized cells of the gonads, bone marrow, skin, and alimentary canal)	Highly sensitive
Alveolar cells (lung cells that absorb oxygen), bile cells (digestive track), and kidney	Sensitive
Endothelial and the circulatory system cells (which line the cavities of the body such as hear and blood vessels)	Intermediately sensitive
Connective tissue such as muscle, bone, and nerve cells	Resistant to damage

Gamma-ray radiography is a major use of radioactive sources, especially for thick materials. The gamma-ray sources often used in gamma-ray radiography are shown in Table 2 along with their various characteristics.

[1] Level III Study Guide, Radiographic Method, published by the American Society for Nondestructive Testing, Columbus, OH 43228, page 40.

Table 2. Characteristics of Four Widely Used Radiographic Isotopic Sources2

Characteristics	**Cobalt 60**	**Cesium 137**	**Iridium 192**	**Thulium 170**
Half-life	5.27 yrs	30.1 yrs	74.3 days	129 days
Chemical form	Co	CsCl	Ir	Tm_2O_3
Density (g/cc)	8.9	3.5	22.4	4
Gamma-ray energy (MeV)	1.33 1.17	0.66	0.31 0.47 0.60	0.084 0.052
Typical steel thickness range over which source is used	0.5 -6”	0.5-4”	0.4 to 1.5”	
Gamma-rays per disintegration	1.0 1.0	0.92	1.47 0.67 0.27	0.03 0.05
Beta ray energy (MeV)	0.31	0.5	0.6	1.0
R/hr-m per curie (mSv/h-m per gig Becquerel)*	1.35 310	0.34 80	0.55 125	0.0030 0.7
Linear self-absorption coefficients (cm^{-1}) Neutrons Gamma	 3.0 0.22	 - 0.1	 33 5.1, 2.1, 1.4	 1.5 22.0, 17.6
Ultimate specific activity in Ci/g* (GBq/g)	1200 44,000	25 925	10,000 370,000	6,300 230,000
Practical specific activity in Ci/g* (GBq/g)	50 1,850	25 925	350 13,000	1,000 37,000
Practical curies per cc GBq/cc	450 17,000	90 3,300	8,000 300,000	4,000 150,000
Practical R/hr-m per cc MGy/h-m per cc	600 6,000	33 3,300	4,400 44,000	10 100
Practical radiographic sources (Ci) Becquerel	20 740	75 2,800	100 3700	50 1,750
Approximate diameter, mm (in)	3 (0.1)	10 (0.4)	3 (0.1)	3 (0.1)
Typically required Uranium Shielding (lb)	500	120	45	2

[2] Level III Study Guide, Radiographic Method, published by the American Society for Nondestructive Testing, Columbus, OH 43228, page 22. *R is Roentgen a standard for radiation exposure and will produce an ionization that represents the absorption of 83 ergs of energy. Rem is the acronym for roentgen equivalent man and is defined as the quantity of ionizing radiation of any type that, when absorbed in a biological system, results in the same biological effects as one unit of absorbed dose in the form of low linear energy transfer radiation. In the Standard International System of Units (SI), 1 siefert (Sv) = 100 mrem. Rad is an acronym for radiation-absorbed dose and represents energy absorption of 100 ergs/gm of material. In the SI units, 1gray (Gy) = 100 rad. A Curie (Ci) is $3.7x10^{10}$ disintegrations per second. A Becquerel is 1 disintegration per second, so 1 curie = $3.7x10^{10}$ Becquerel’s.

1.2 How Isotope Sources Are Used

Isotope sources are used for a number of applications, including thickness gauging and radiography. Most often the application is based upon a through-transmission mode, shown in Figure 1, where the radiation source is on one side of the object being gauged or radiographed and the detector or film is on the other side of the object[3]. The concept is that gamma rays from the source will pass through the object and a portion of the x-ray will be absorbed in proportion to the density of the material in the object. Material with higher density will absorb more gamma rays.

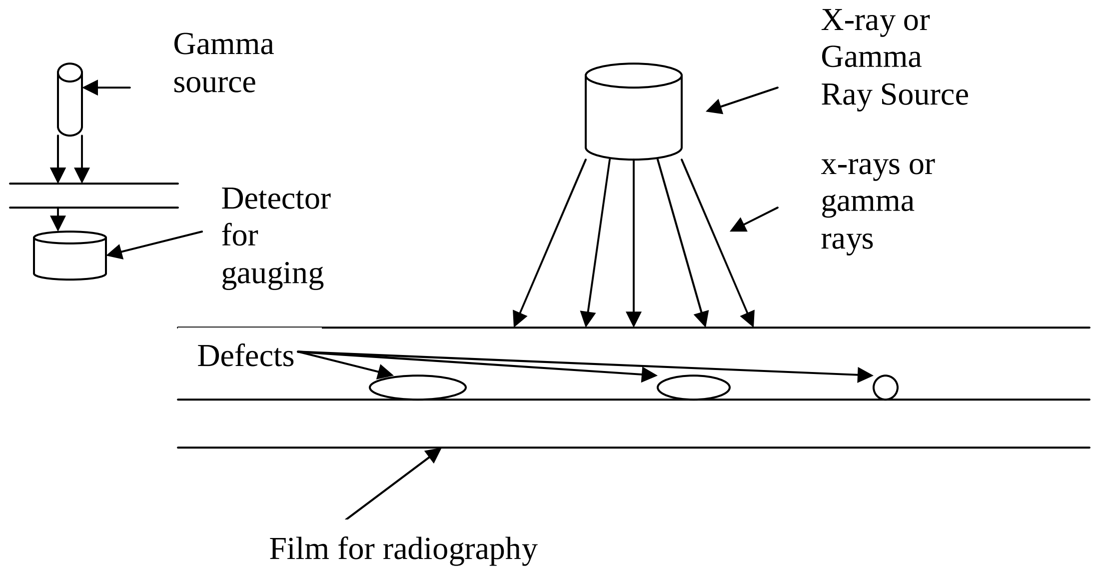


Figure 1. Illustrations of the through-transmission mode of gamma ray radiography or gauging

For example, in a radiograph, if the object is steel (density of approximately 7.8 g/cc) and there are areas where voids exist (voids have the density of air, approximately 0.0013 g/cc), then the voids will absorb fewer gamma rays than the steel and more gamma rays will penetrate the film. The equation for absorption is

$I = I_o e\text{-}\mu t$,

[3] Level III Study Guide, Radiographic Method, published by the American Society for Nondestructive Testing, copyright 1988, page 72

where I is the portion of the initial intensity of gamma rays, I_0, passing through a material with linear absorption μ and thickness t. If the material is of constant density, it is easy to see how the thickness of a part could be easily determined by the expression $t = \ln(I_0/I)/\mu$. Since radiation detectors respond very quickly, this type of thickness gauging is very useful. In addition, there is no need for couplant (associated with ultrasonics) and this technique is not sensitive to lift-off since the density of air is so small compared to most other materials for which thickness is being gauged.

The advantages of using gamma ray sources include portability and the ability to penetrate thick materials in a relativity short time. As shown in Table 2, cobalt has x-ray lines at 1.17 and 1.33 MeV, cesium has an x-ray line at 0.66 MeV, and iridium has x-ray lines at 0.31, 0.47.and 0.60 MeV. These gamma ray sources do not require the use of electrical power to generate the gamma rays.

The disadvantages include shielding requirements and safety considerations. Depleted uranium is used as a shielding material for sources. The storage container (camera) for iridium sources contains 45 pounds of shielding materials. Cobalt requires 500 pounds of shielding. Cobalt cameras are often fixed to a trailer and transported to and from inspection sites. Iridium is used whenever possible, and not all companies using source material will have a cobalt source. Because source materials constantly generate very penetrating radiation, considerable damage can be done to living tissue in a short time. Technicians must be trained in the potential hazards associated with use of gamma radiography to themselves and to the public.

Federal or State jurisdictions regulate source materials because of safety issues. The Nuclear Regulation Commission (NRC) has developed and enforces regulations for source materials. The NRC allows states to regulate materials if they follow NRC guidelines. These states are identified as "Agreement States." In either case, obtaining and maintaining a license is a costly and well regulated process that protects workers and the public from the hazards of gamma radiation.

As can be imaged, the safe handling of these sources is of key importance for personnel safety, and, since radiation exposure cannot be felt, it is difficult to know when exposure might occur. Most inspectors who use radiographic sources carefully follow handling procedures and regulations established by the NRC. However, alternative inspection technologies might be useful in minimizing unknown or unexpected exposure.

Gamma ray and x-ray radiography have been industry standards since the early 1900s because this technology provided a “shadow image” that is easy to interpret. Other inspection technologies, such as ultrasonics and eddy current, can provide similar information about an object, but often rely on images constructed from amplitude scans, and these do not look like x-ray shadow images. An example of a conventional ultrasonic c-scan image is shown in Figure 2.

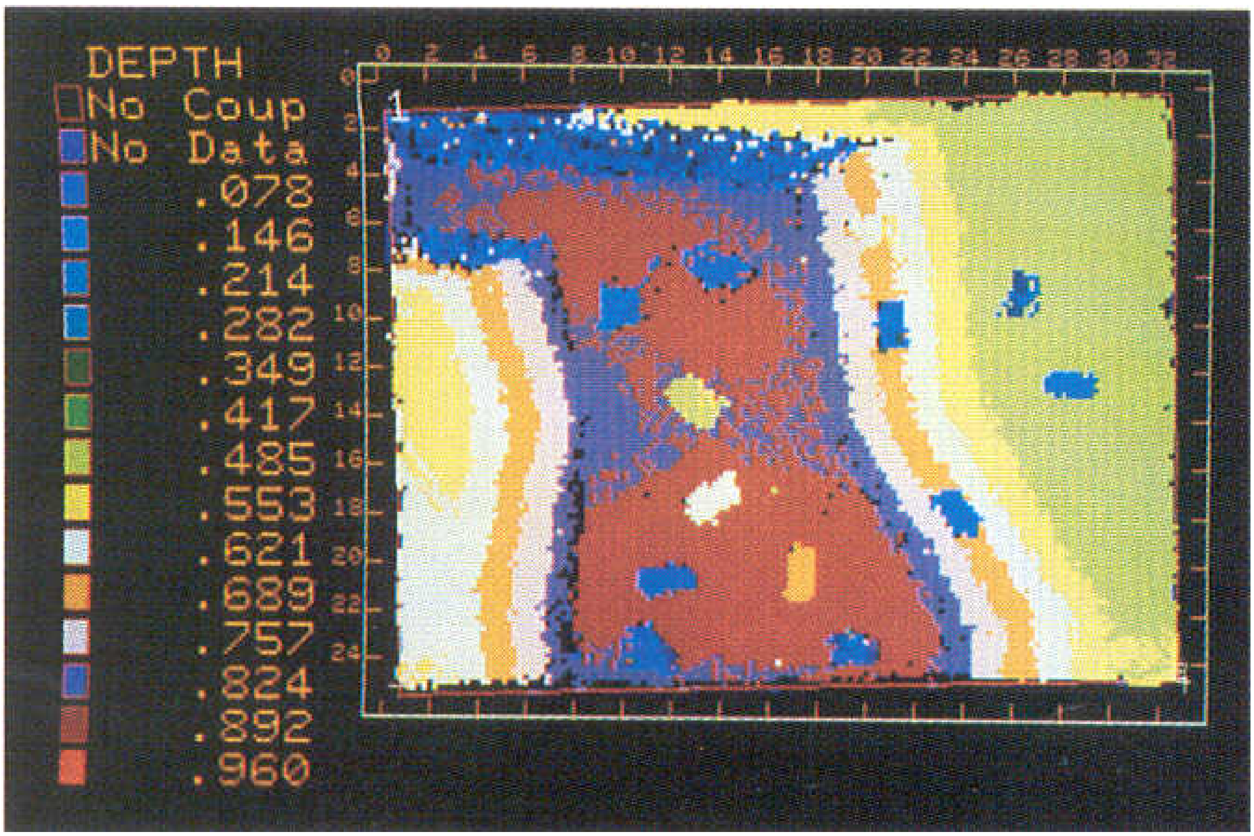
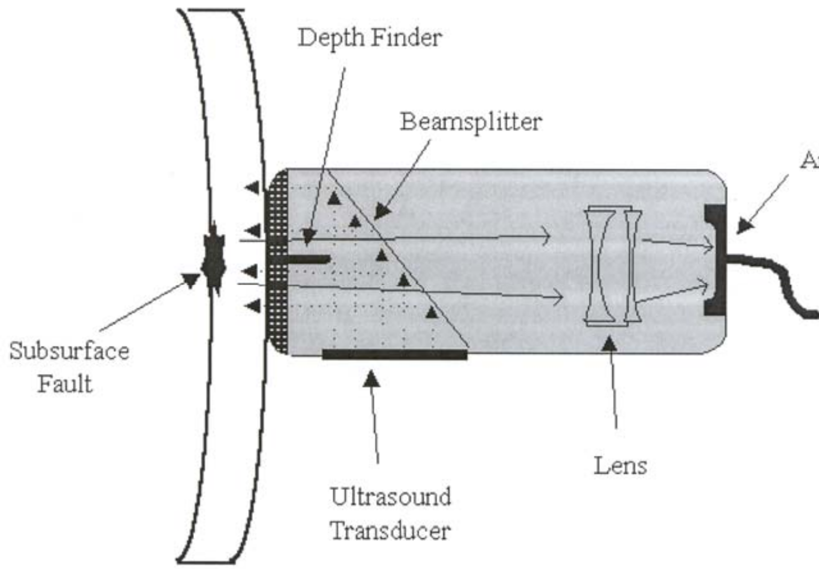


Figure 2. Illustration of a conventional ultrasonic C-scan image. This image shows a top view of a wing surface and several subsurface defects (yellow and orange are deep; blue is near surface).

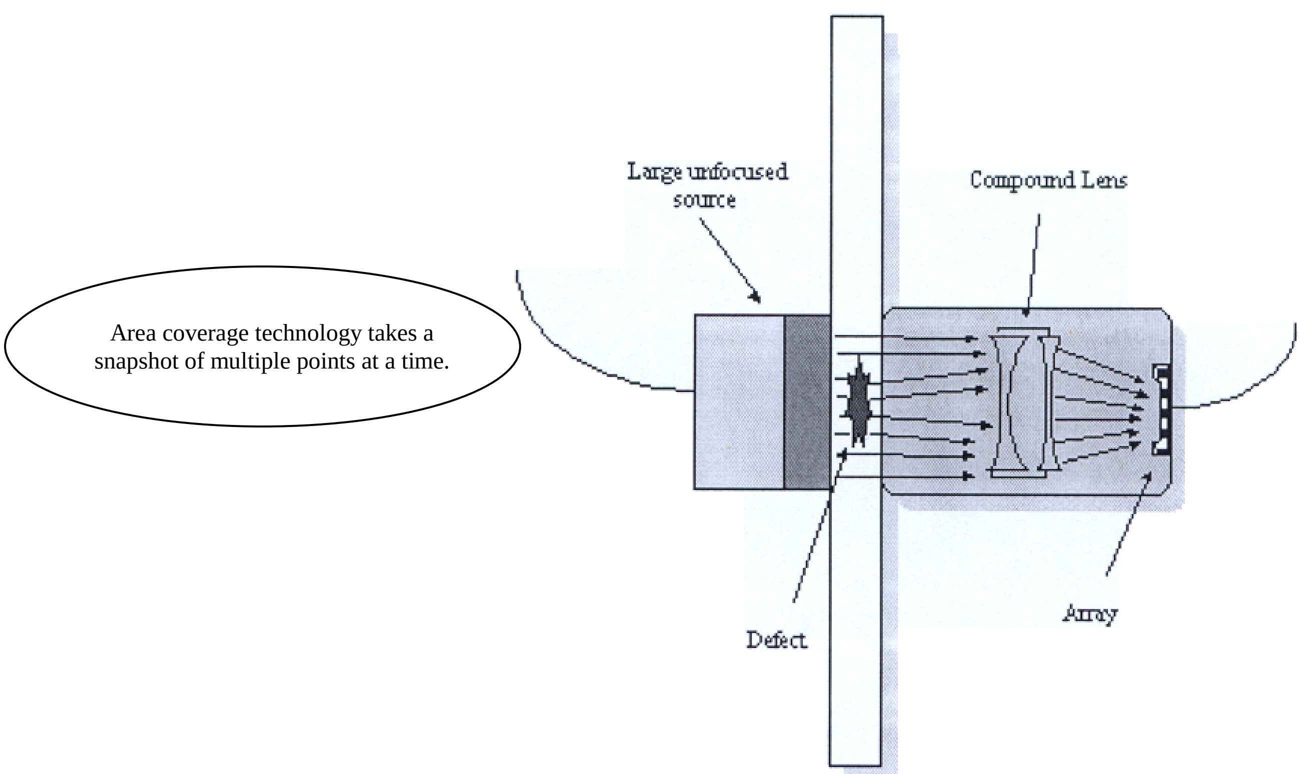
1.3 What Alternatives

In the mid-1990’s, two notable improvements in ultrasonic technology were made. First, several ultrasonic imaging camera systems were developed that allow the ultrasonic energy to be directly deposited onto a CCD camera chip that then produced an image similar to the x-ray shadow image. This technique is illustrated in Figure 3.

The images produced by the first ultrasonic imaging camera provided poor spatial resolution and gray-scale sensitivity as compared to the nominal quality of CCD camera images. However, within the last few years, the ultrasonic imaging camera technology has improved so that the images produced look more like visual or radiographic images, as illustrated in Figure 4.



(a)



(b)

Figure 3. Illustration of the internal working of the ultrasonic imaging cameras developed by Imperium, Inc., in (a) pulse-echo mode and (b) through-transmission mode

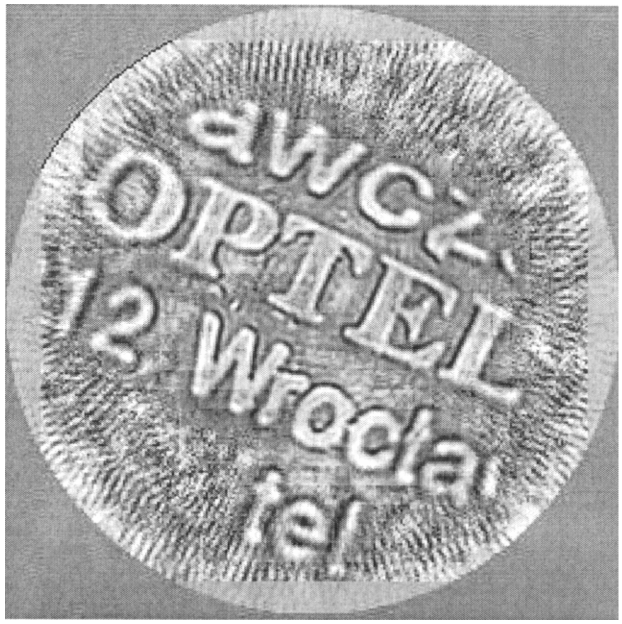


Figure 4. Image of a "stamp" obtained using a laboratory version of an ultrasonic imaging camera developed by Wiesław Bicz*, Dariusz Banasiak, Paweł Bruciak, Zbigniew Gumienny***, Stanisław Gumuliński, Dariusz Kosz, Agnieszka Krysiak, Władysław Kuczyński, Mieczysław Pluta***, and Grzegorz Rabiej working for Optel Ltd.**

The second improvement was the development of ultrasonic transducers (and associated electronics) that were better matched to air and, thus, allowed the use of ultrasonic inspection technology without liquid couplant (this is called air-coupled ultrasonic technology).

Based upon these improvements in the ultrasonic imaging cameras and airborne ultrasonics, it is now believed that these technologies might be more comparable to x-ray radiography and would therefore have the potential to replace the use of radioactive sources for x-ray radiography imaging and thickness gauging, and thus greatly reduce a segment of applications where a large amount of isotopic sources are presently used.

2.0 TECHNICAL OBJECTIVES OF THE FUNDED WORK

The EPA was looking for ways to reduce the industrial need and use of radioisotope sources. The EPA funded Southwest Research Institute (SwRI) to:

(1) Investigate the state of the art of ultrasonic imaging systems and compare them (both through specifications and limited laboratory demonstrations) to radiography.

(2) Provide preliminary data that shows the technical community that ultrasonic imaging could, in some cases, replace radiography.

(3) Provide a preliminary list of other applications where ultrasonic imaging could be used in lieu of radiography to make the case for reducing the need for radiography sources.

3.0 TECHNICAL DISCUSSION

The technical approach used by SwRI to meet these objectives included (1) identifying advanced state-of-the-art ultrasonic imaging cameras, (2) performing laboratory comparisons of imaging capabilities between ultrasonics and x-ray radiography, (3) providing a final report comparing radiographic imaging to ultrasonic imaging, and (4) providing a list of applications where non-isotopic source solutions might be available. The results obtained are discussed in Section 3 of this final report.

3.1 Specifications for Image Quality of Radiographs Compared to Ultrasonic Camera

Table 3 shows characteristics that were developed as a means to compare film radiography, digital (or real time) radiography, and ultrasonic camera imaging.

Table 3. Specifications for Image Quality of Radiographs Compared to Ultrasonic Camera

Characteristic	Film Radiography	Digital Radiography	Ultrasonic Camera Imaging	Comments
Optical image quality	Up to 10 lpmm* (depending on film type)	Up to 4 lpmm	Approximately 2 lpmm (at 5MHz)	In radiography, crack must be parallel to radiation beam; in ultrasonics, slight off-axis provides better detection
Time required to obtain image	2-10 minutes exposure (depending on part thickness) plus 5-20 minutes for film processing	2-10 minutes exposure (depending on part thickness) with no film processing	Less than one minute	
Access around part under inspection	Both sides required	Both sides required	One side only	
Special handling	Radiation license required as well as roped off area during exposure (roped off area may be 20 ft. radius or more)	Radiation license required as well as roped off area during exposure (roped off area may be 20 ft. radius or more)	No special handling, Inspection occurs on part	No license required for ultrasonics

Characteristic	Film Radiography	Digital Radiography	Ultrasonic Camera Imaging	Comments
Requirements for touching the part under inspection	None	None	Must apply liquid couplant to part under inspection	Airborne ultrasonic can detect delaminations, but not provide an image
Field of View	Large field of view in each film image (up to 14” by 17”	Depends on imager, ranges from 4” to 12” in diameter	Approximately 1” by 1”	Imaging process occurs quickly for ultrasonic camera and there is no need to wait for film

*lpmm means line pair per millimeter

3.2 Identifying Advanced State-of-the-Art Ultrasonic Imaging Cameras

SwRI conducted a literature review for the purpose of identifying manufacturers of advanced state-of-the-art ultrasonic imaging cameras. An ultrasonic camera was defined as a “device that uses a piezoelectric crystal to convert ultrasonic sound waves, transmitted through a subject, into a voltage that modulates the electron beam of a cathode-ray tube.” Three ultrasonic imaging cameras were found: (1) Imperium, Inc, (2) Matec Microelectronics, and (3) INEEL. The Imperium camera, called the Acoustocam 1180 is shown in Figure 5. It is a hand-held, portable unit used primarily in the pulse-echo mode (only one sided access is needed). The Matec camera is shown in Figure 6 and must be used in the through-transmission mode. The unit consists of a camera, a transducer (that is approximately 3 inches in diameter) and the imaging electronics with video monitor. The INEEL unit illustrated in Figure 7 is clearly not portable and could not be easily used in a real-world inspection application. The concept of how the INEEL camera works is illustrated in Figure 8.

Figure 5. Photograph showing the Acoustocam 1180 developed by Imperium, Inc.

Figure 6. Photograph of the Matec camera used in the through-transmission mode

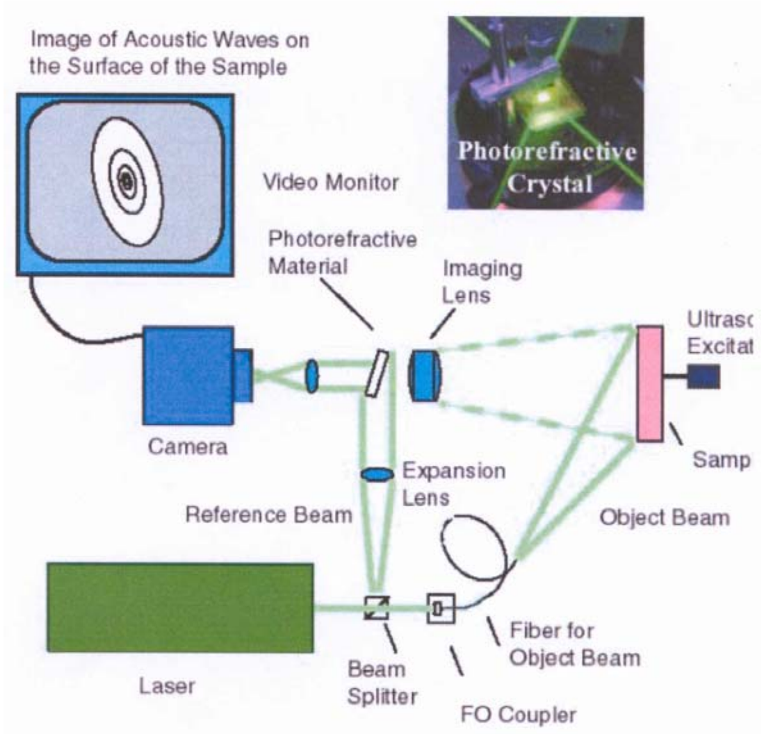


Figure 7. Photograph of the INEEL unit, which clearly shows that it is not a portable unit

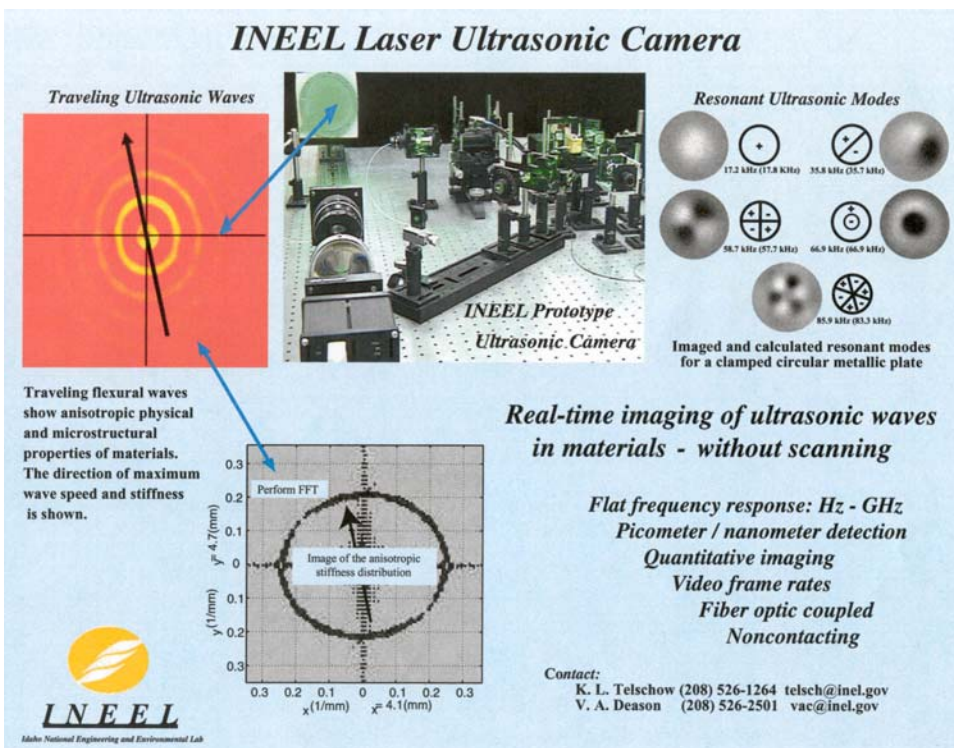


Figure 8. Illustration of how the INEEL camera works

3.3 Performing Laboratory Comparisons of Imaging Capabilities between Ultrasonics and X-ray Radiography

Five test samples were used to compare images produced by radiography with ultrasonic imaging cameras. Test Sample A was a steel plate that was 18 inches by 15 inches by ½ inch with a large number of round bottom holes (RBHs) to simulate corrosion. Test Sample B was a steel plate that was 15 ½ inches by 8 inches by 5/8 inch with a number of surface notches. Test Sample C was a steel pipe weld section that was 9 by 7 ½ by 1 1/8 inches. Test Samples D and E were honeycomb samples that were approximately 6 inches by 6 inches by 1 inch.

A photograph of the underside of Test Sample A is shown in Figure 9. There are seven rows of RBHs drilled into the plate. The dimensions of the RBHs are given in Table 4. The diameter of the holes increased from A to G, and depths increased from Column 1 to Column 5 (with Column 5 being the deepest). The radiograph of Test Sample A (shown in Figure 10) was taken using a Sperry 300 x-ray source set a 220Kv, 9.8 mA, a 48 " source to film distance (with Test Sample A laying on top of the film). The film used was Kodak T and the exposure time was 2 minutes. The x-ray radiographic image was obtained using two pieces of film and the image shown in Figure 10 is a composite of that image obtained by lining up the round bottom holes shown in both films. In the radiograph, all the RBHs are clearly and sharply visible. To get this image, access to both sides of the plate was required.

The ultrasonic imaging camera was also used to image Test Sample A. It was initially assumed that the pulse-echo, hand-held Acoustocam 1180 would be available for the image collection process. However, on the day the tests were conducted, the Acoustocam 1180 was not available, so the internal imaging portion of the Acoustocam 1180 was used in an immersion tank to collect 0-degree, longitudinal-wave images. It is important to note that the ultrasonic imaging camera images approximately a 1- by 1-inch area, so it does not have the capability to show in one image an area much larger than 1 inch by 1 inch. To image an entire sample as large as Test Sample A, multiple 1- by 1-inch areas were imaged and the images pasted together as shown in Figure 11. The RBHs are clearly evident in the image obtained using the Acoustocam 1180 and even more detectable when the video image is observed. Though the "still" image obtained by the Acoustocam 1180 is not as clear as either the radiograph or the photograph, the general nature of the RBHs is certainly observable in the image. The circular nature of the RBHs does not lend itself to testing the image resolution capability of the ultrasonic imaging camera as well as narrow and multi-faceted notches do.

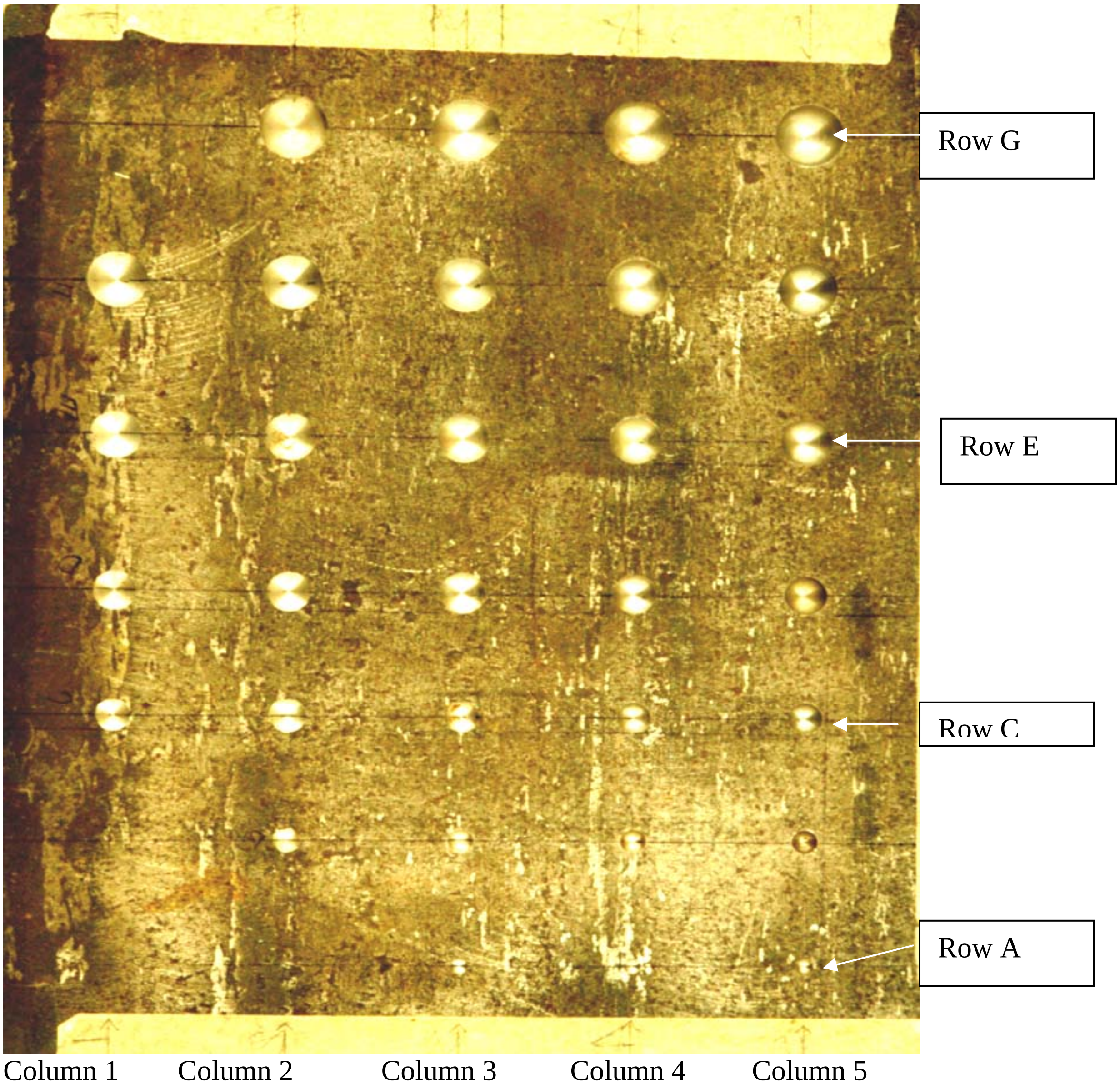


Figure 9. Photograph of the back of Test Sample A with multiple round bottom holes. As expected, the radiograph and photograph match very well.

Table 4. Dimensions of Round Bottom Holes in Test Sample A

Row	Diameter	Range of Hole Depths (inch)
A	0.25	0.3 0.1 0.04
B	0.375	0.16 0.08 0.04 0.03
C	0.500	0.25 0.10 0.08 0.060 0.03
D	0.625	0.30 0.170 0.080 0.06 0.03
E	0.750	0.37 0.18 0.14 0.10 0.06
F	0.875	0.42 0.23 0.20 0.17 0.12
G	1.0	0.48 0.35 0.25 0.18

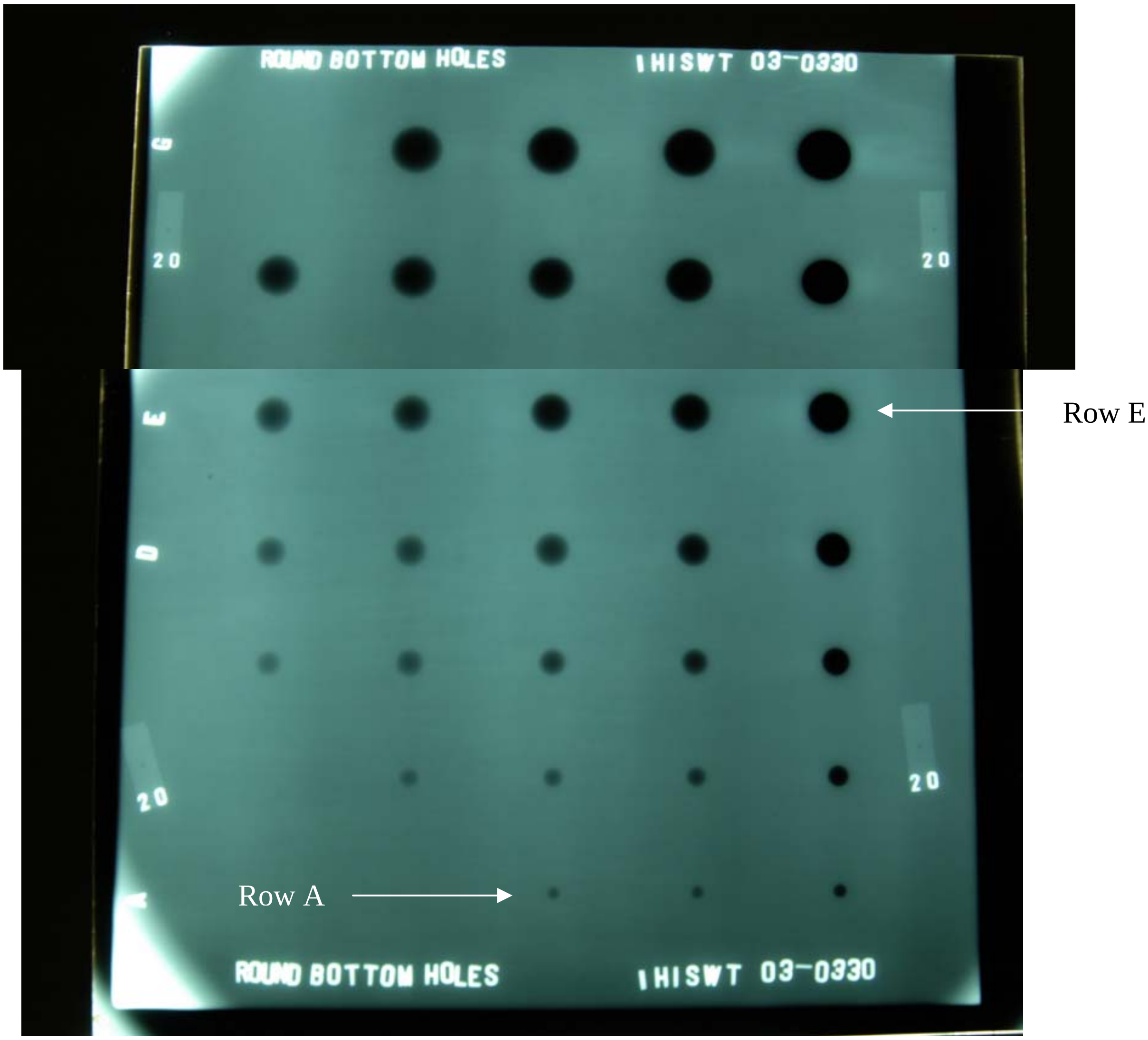


Figure 10. Two radiographs of overlapping sections of Test Sample A with multiple RBHs. Notice that rows E and D are in both the upper and lower radiograph. The radiographs were taken with an x-ray source with a source-to-film distance of 48 inches with 220Kv, 9.8mA, and an exposure of 2 and 2 1/2 minutes using Kodak T film.

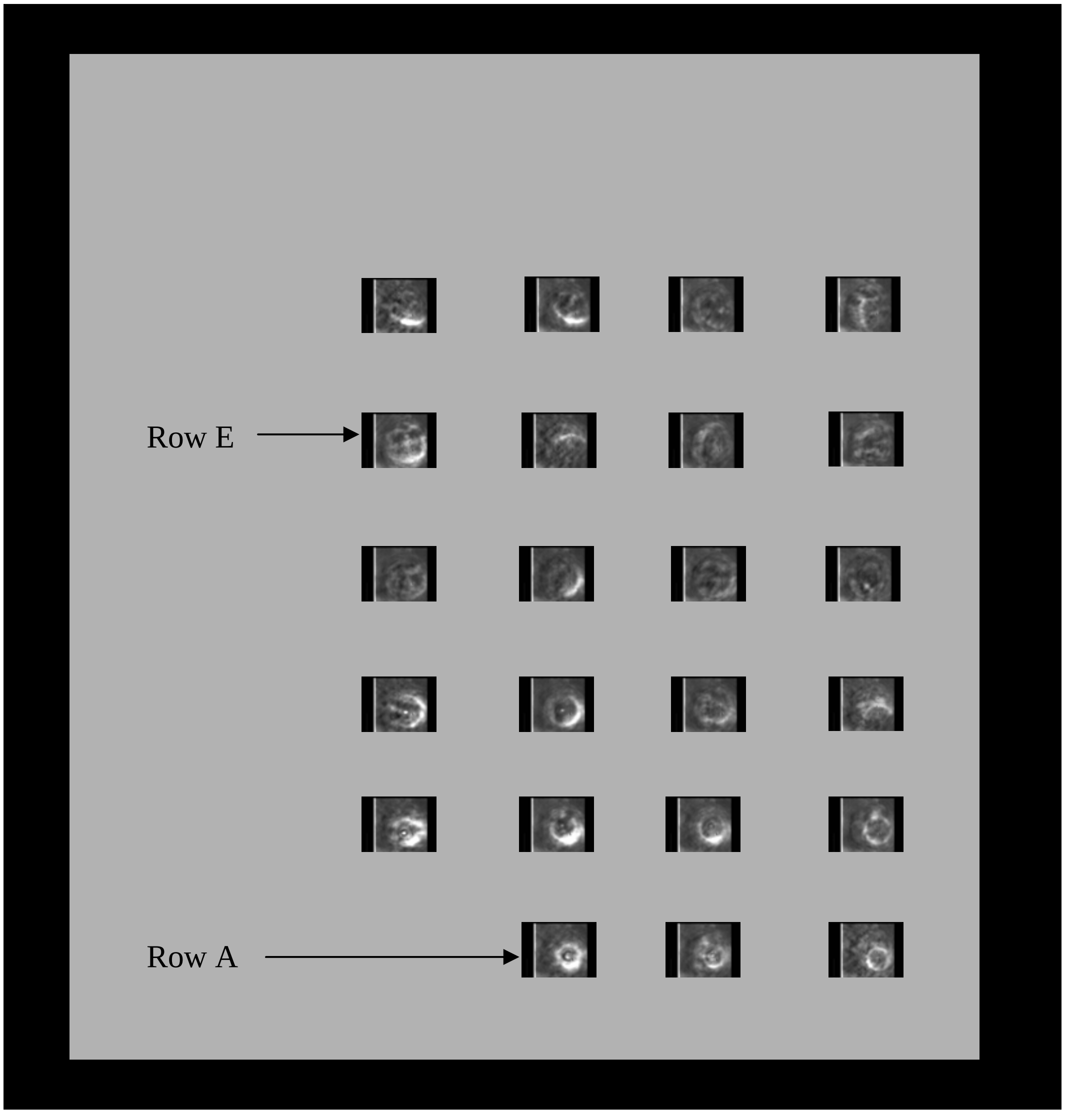


Figure 11. Composite image of Test Sample A developed by pasting the 1- by 1-inch images of the various RBHs shown in Figures 7 and 8 obtained using the Acoustocam 1180 ultrasonic imaging camera. The images were pasted onto a gray background that simulated the approximate overall size of Test Sample A and the approximate relative location of the RBHs. Ultrasonic images of Column 1 defects for rows B, C, D, E, and F and all of row G were not obtained because of geometrical constraints in the tank where data were collected.

Test Sample B provided the capability of looking for non-circular defects. Figure 12 is a photograph of the bottom side of Test Sample B, while Figure 13 and Figure 14 show radiographs taken with the Sperry 300 x-ray machine (using the parameters discussed above) and using a ^{192}Ir source with a source-to-film distance of 20 inches and an exposure time of 90 seconds with F-80 film. The gamma ray energies of ^{192}Ir are 0.31 MeV, 0.47 MeV, and 0.60 MeV. As expected, the image obtained with the ^{192}Ir source is not as good as that obtained with x-ray source; however, the narrow, multi-faceted nature of several of the notches is clear on both radiographs. The images obtained with the Acoustocam 1180 pasted together into a composite image are shown in Figure 15.

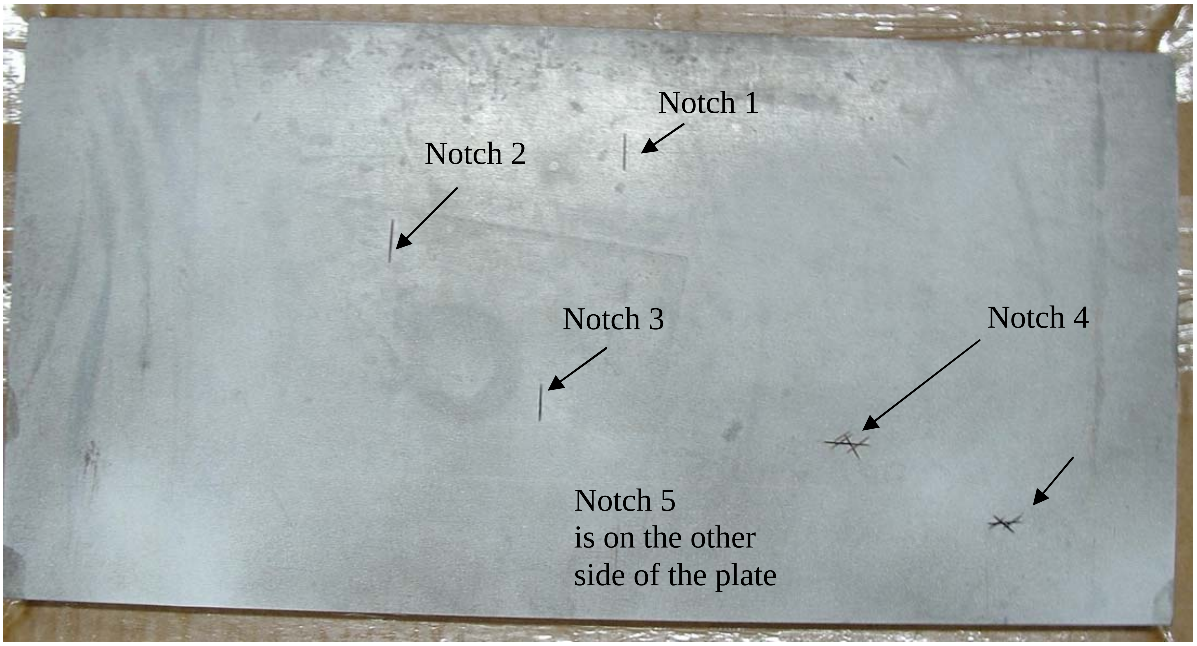


Figure 12. Photograph of Test Sample B showing the narrow and multifaceted nature of six notches.

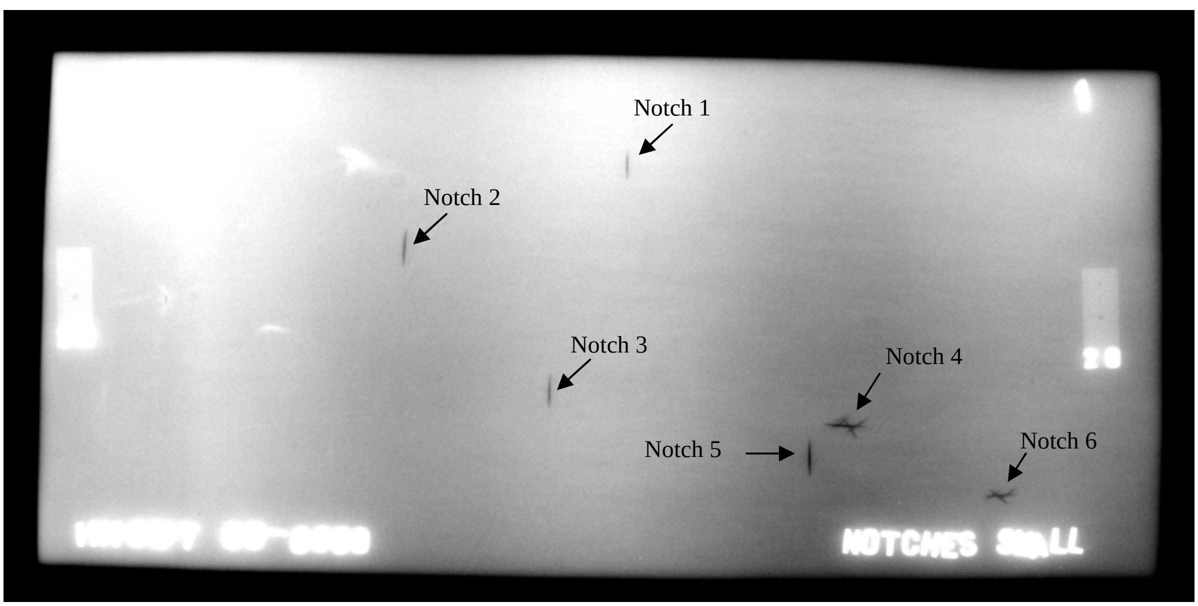


Figure 13. Radiograph of Test Sample B with many surface notches, using an x-ray source (with a source-to-film distance of 48 inches at 220Kv, 9.8mA, and an exposure of 2 and 2 1/2 minutes using Kodak T film)

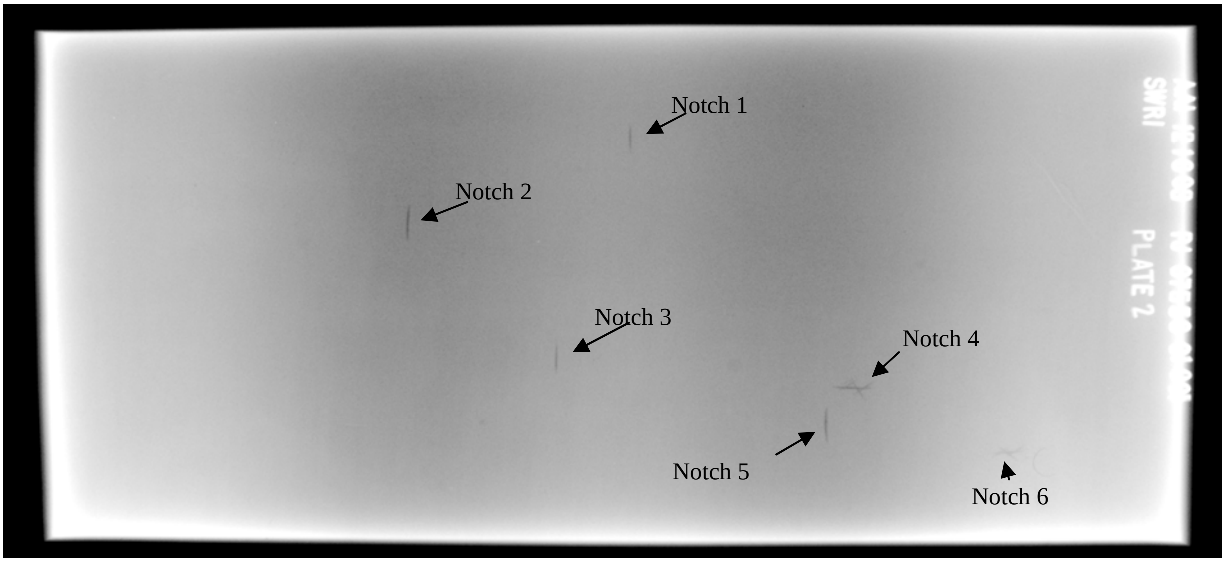


Figure 14. Radiograph of Test Sample B with many surface notches using iridium 192 isotope source. The gamma ray energies of ^{192}Ir are 0.31 MeV, 0.47 MeV, and 0.60 MeV

The composite image shown in Figure 15 clearly shows the narrow and multifaceted nature of the defects. This is much more like an optical image than an image obtained using a conventional ultrasonic c-scan amplitude image, which would be more of a colorful oval shape in almost each of these cases. Again, the realtime image nature of the ultrasonic imaging camera output makes it easier to identify the defect than the fixed computer file of the image shown in the composite image. Figure 16 shows the conventional ultrasonic c-scan image of the internal and lower surface of Test Sample B. Notice that the detail of the geometric configurations of the notches are not as clear in the c-scan as the ultrasonic camera image. From Figure 17, although it is clear that the radiographic image best represents the visual image for the various defects, the ultrasonic camera image does show the nature of the defect much better than the conventional c-scan ultrasonic image.

A photograph of Test Sample C is shown in

Figure 18 and the radiograph of Test Sample C is shown in Figure 19. The radiograph was obtained with the ^{192}Ir source using an exposure of 100 seconds with F-80 film. Unfortunately, the Acoustocam 1180 was not working properly at the time the plate was available and, therefore, no ultrasonic image was obtained. However, it is believed that if the Acoustocam 1180 was working properly, it could have been used to obtain an image.

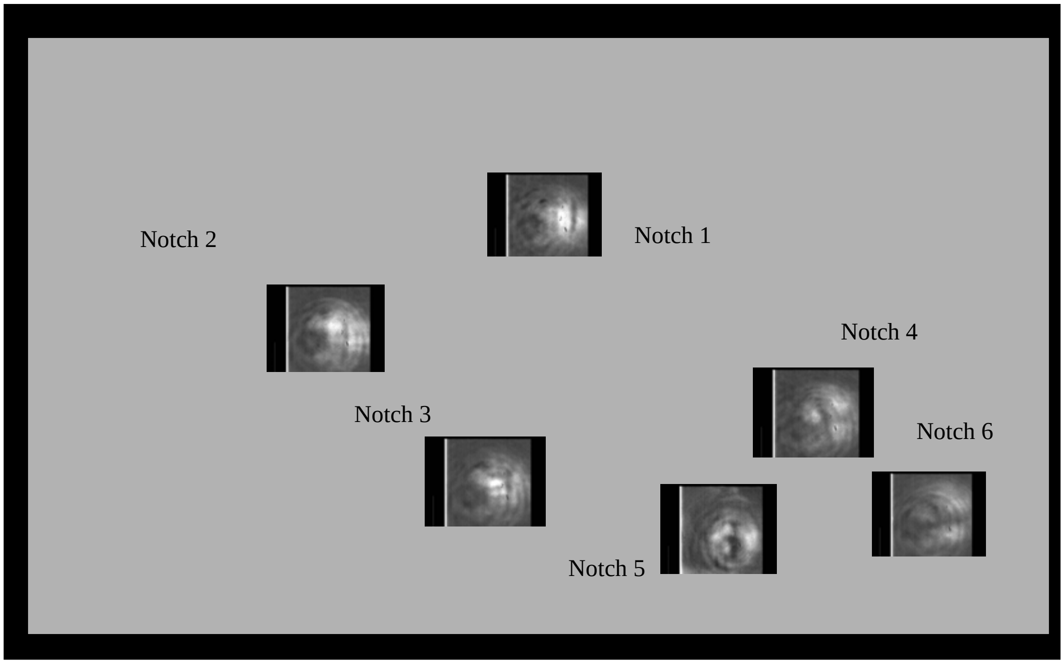


Figure 15. Composite image generated by pasting the images of notches in Test Sample B obtained using the Acoustocam 1180 onto a background of the approximate size of Test Sample B. Notice that the Acoustocam 1180 images have the proper structure of the notches and especially notches 4 and 6 which appear to be several crossed notches. This is much more like an optical image than an image obtained using a conventional ultrasonic c-scan amplitude image.

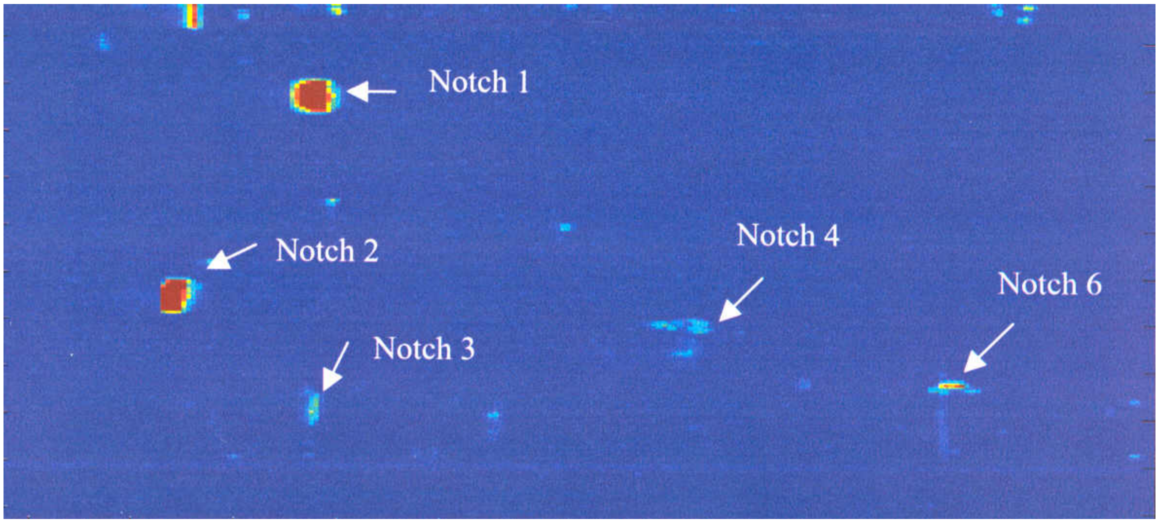


Figure 16. Ultrasonic c-scan of Test Sample B showing internal indications as well as indications on the lower surface of the test sample. Notches 1, 2, 3, 4, and 6 are clear. Notch 5 is not detected since it was on the upper surface. The upper surface has many indications due to surface roughness reflections. Also note that it is difficult to determine much about the actual geometry of the indication from the ultrasonic c-scan.

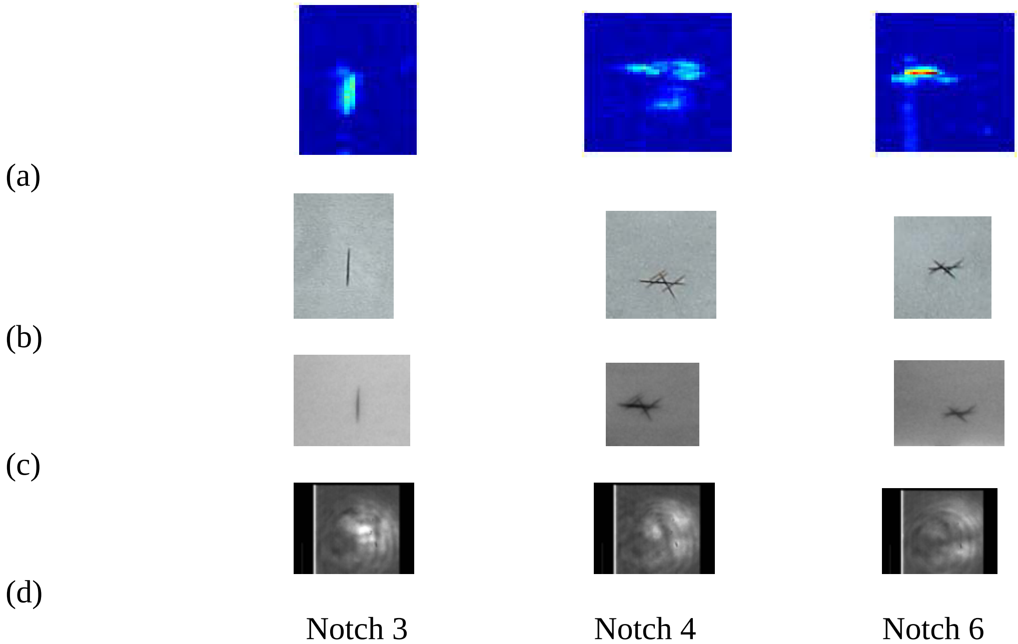


Figure 17. Comparison of the images obtained from (a) conventional ultrasonic c-scan, (b) visual, (c) radiograph, and (d) ultrasonic camera. Notice that the ultrasonic camera image is a much better representation of the defect than the conventional ultrasonic c-scan.

Newer generation imaging arrays are now being used to provide greatly improved ultrasonic images. Development into better imagery will continue over the coming months and years.

Similar data were collected on two honeycomb samples, Test Samples D and E. The honeycomb samples were approximately 6 inches by 6 inches and approximately 1 inch thick. A photograph of Test Sample D is shown in Figure 20, and the radiograph of the honeycomb sample is shown in Figure 21. The radiograph was taken using the Sperry 300 x-ray machine at 60 Kv, 5 mA, and 30-second exposure with Kodak T film (with a 48-inch source-to-film distance).

The ultrasonic camera image is shown in Figure 22. This image clearly shows the crushed honeycomb region. Similar data obtained for Test Sample E are shown in Figure 23, Figure 24, and Figure 25. The ultrasonic images are remarkable because they show honeycomb detail very similar to the radiographs.

(a)

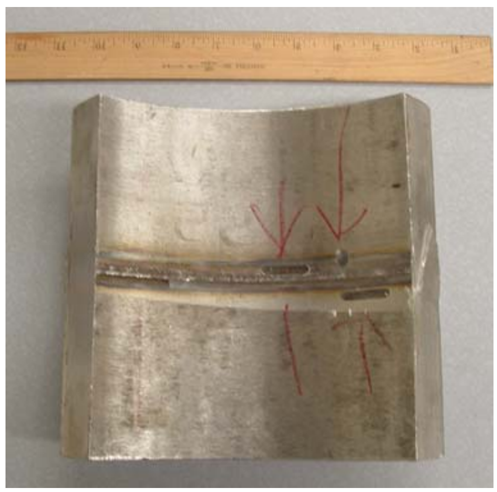


Figure 18. Test Sample C: (a) top view and (b) bottom side

Figure 19. Radiograph of Test Sample C that was a 9-inch by 71/2-inch by 1 1/8-inch test block taken with a ^{192}Ir source, an exposure of 100 seconds, and F-80 film.

Figure 20. Photograph of honeycomb Test Sample D

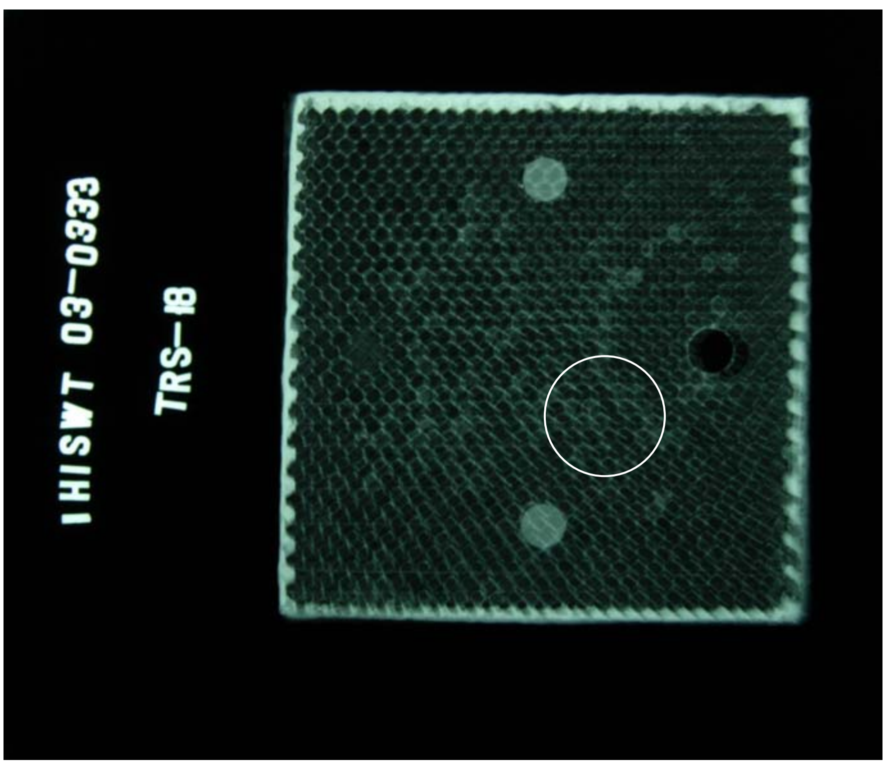


Figure 21. Radiograph of honeycomb composite with crushed core and delamination inserts

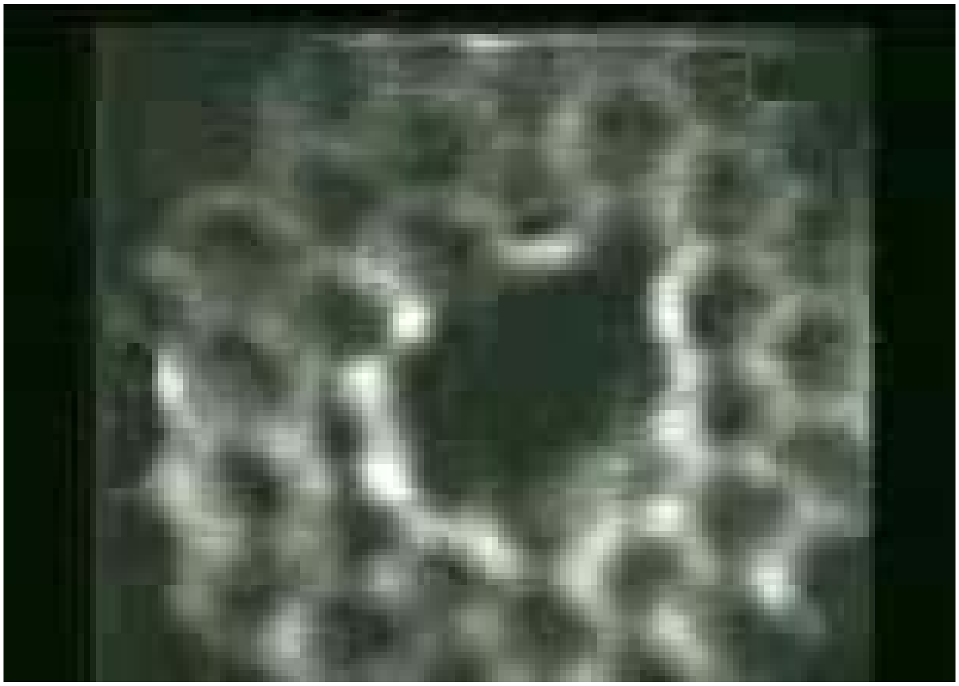


Figure 22. Ultrasonic camera image of damaged area in a honeycomb composite panel (shown in circled area in Figure 21).

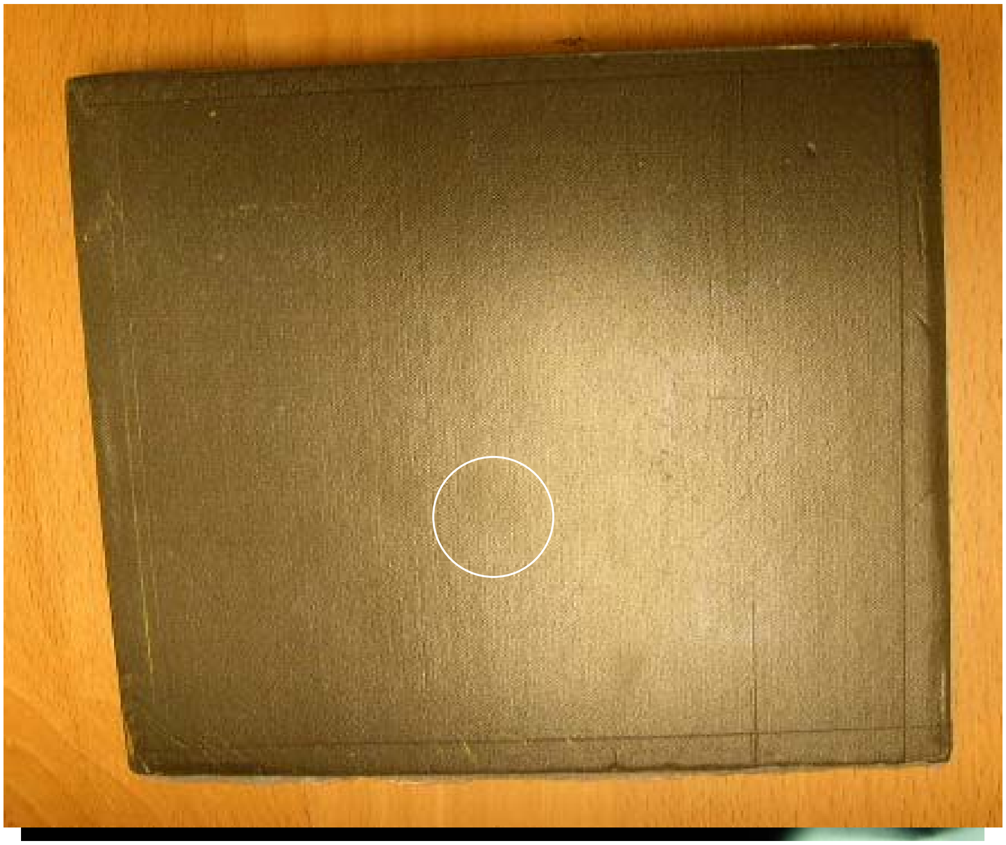


Figure 23. Photograph of honeycomb Test Sample E with delamination insert

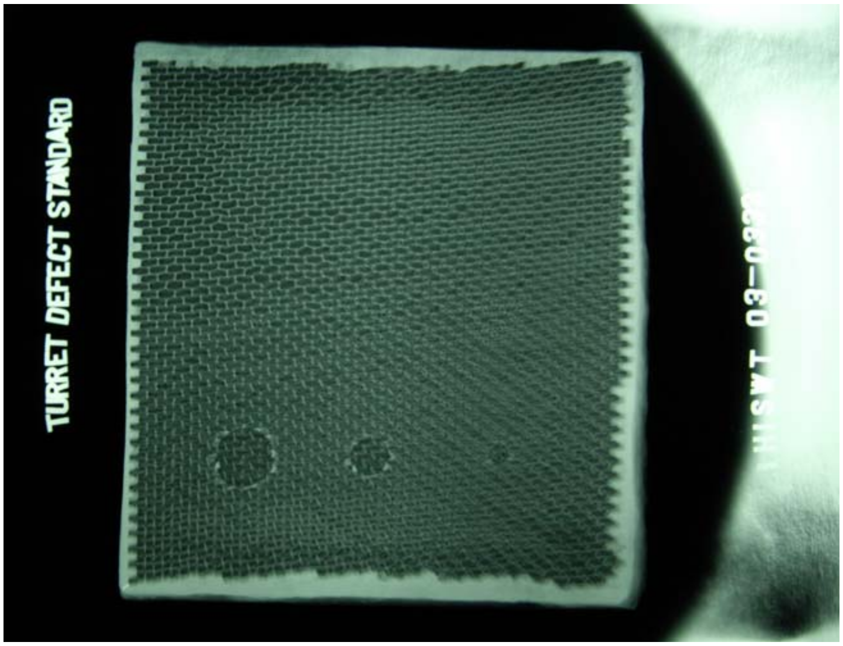


Figure 24. Radiograph of honeycomb Test Sample E with delamination insert

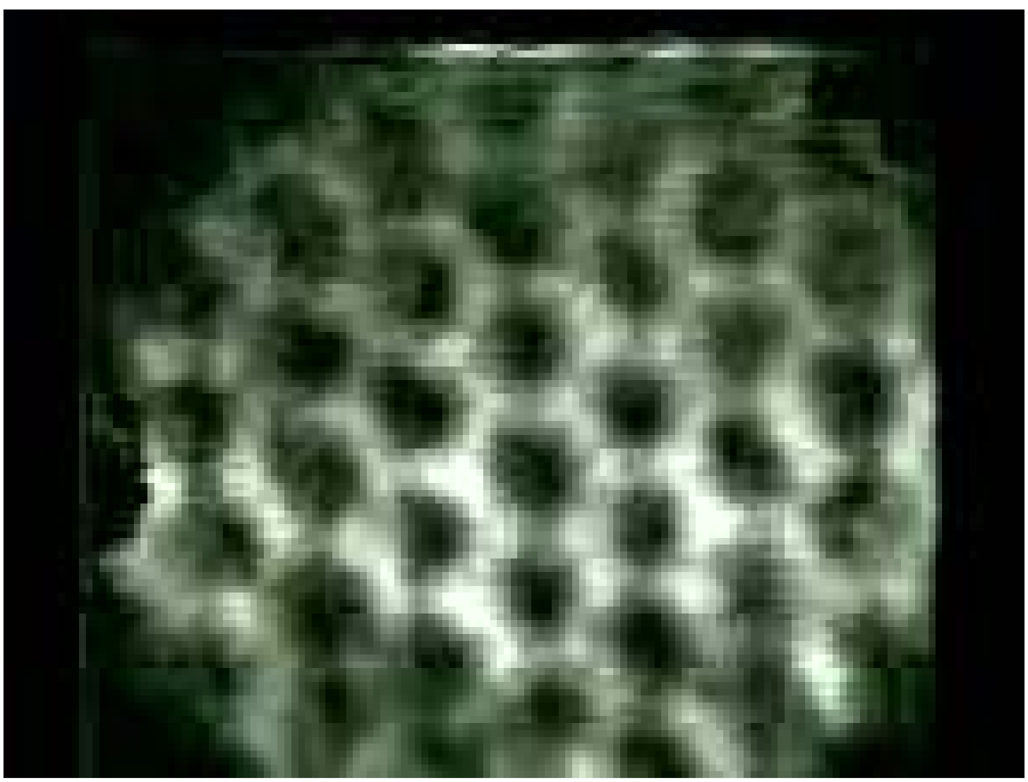


Figure 25. Ultrasonic camera image of a honeycomb composite panel with no damage (region imaged is the circled area in Figure 23)

In an attempt to review the advantages and disadvantages of using radiography as compared to an ultrasonic imaging camera, the information shown in Table 5 was collected.

Table 5. Comparison of Radiography with Ultrasonic Imaging Cameras

Radiography		Ultrasonic Camera	
Advantages	**Disadvantages**	**Advantages**	**Disadvantages**
Clear image with nearly optical quality	Inhabitable radiation zone around the source and object under test during radiograph exposure	No radiation zone	Images have poor optical resolution (on the order of 0.01 inch)
High quality record	Needs access to both sides of part	Access to only one side needed	
Accepted technology for over 100 years	Film processing chemicals, special environmental issues	No chemicals needed	Cost of the instrumentation is higher than source but lower than x-ray machine
	Cost of the instrumentation	Can get information about defect location as a function of depth	Present systems only provide image of area approximately 1 inch square
	10-30 minutes for radiograph image	Near realtime image	

3.3 Other Potential Applications For Non-isotope Solutions in NDE

One of the major uses of isotope sources is gamma gauging or thickness gauging. For this application, an isotopic source is placed on one side of the material to be gauged and a radiation detector is placed on the other side. There are advantages as well as disadvantages to this approach. The advantages include no need for couplant and no need to touch the part or to be concerned about the separation between the source and part and part and detector (known as lift off). However, one major disadvantage is that for the radiographic gauging, access to both sides of the part is required.

Ultrasonic inspection technology can be used as a replacement technology to measure material thickness. Ultrasonics can be used in a pulse-echo mode with one side of access. The thickness is directly related to the time required for the ultrasonic wave to travel back and forth across the material thickness and the velocity of sound in the material. However, this requires a liquid couplant or a dry coupled wheel and contact between the probe and the part. This means that gauging cannot be conducted for high temperature. An ultrasonic wheel transducer is shown in Figure 26. These wheels work primarily by rolling on the surface to “squeegee” the air away from the wheel and part interface so that the sound is coupled through the rubber wheel material.

Air-coupled transducers have also become available over the last decade and have been shown to provide a good capability to detect changes in transmission through test plates or other objects. However, their practical use for gauging has not been well established. The concept of air-coupled transducers is illustrated in Figure 26. Table 6 lists applications that are presently being investigated and progress made in their potential use.

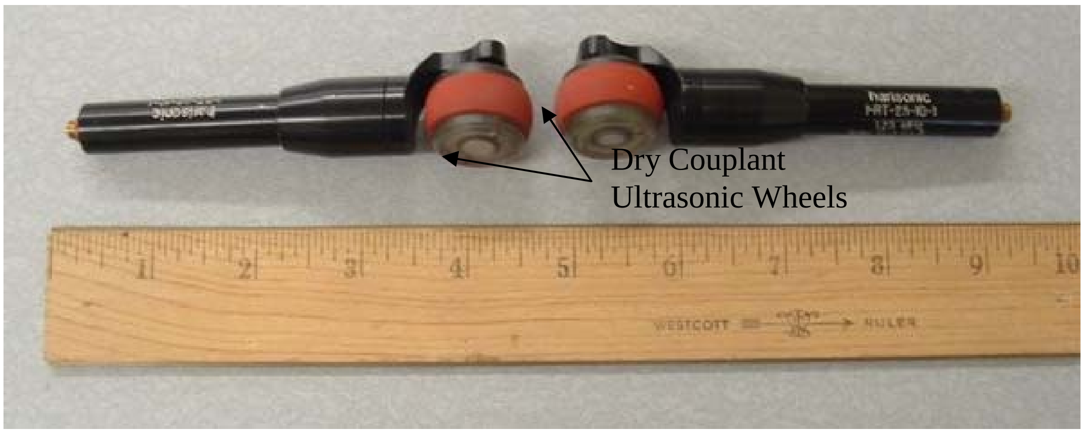


Figure 26. Photograph of two dry-coupled ultrasonic wheels

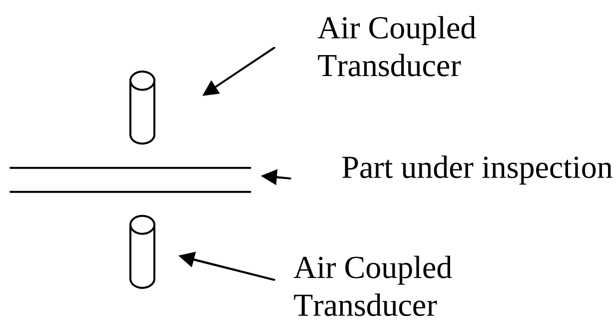


Figure 27. Use of air-coupled transducers to measure material thickness

Work is presently being performed to make sufficient improvements in air-coupled transducer technology so that it might work with one-sided access and no couplant requirement for gauging.

Table 6. Potential Applications of Ultrasonic Transducers to Replace the Need for Isotopic Sources in NDE

Application	Advantages	Disadvantages	Present State of the Art
Thickness gauging using conventional ultrasonics and ultrasonic wheels	Requires access from only one side. No special handling due to isotope source	Requires contact with the part. Cannot be used on high-temperature materials	Presently in use
Thickness gauging using air coupled transducers	Requires access from only one side. Does not require coupling with the part. No special handling due to isotope source	Low signal levels	More work is needed to make this practical

3.4 Another Example of Where a Non-isotope Solution May Exist

There are a variety of areas where radioactive sources are used everyday. Although these sources have a very low intensity, they can still serve as a contamination risk. The purpose of this section is to discuss the smoke detector application where a non-isotope solution can be provided.

Ionization smoke detectors use an ionization chamber and a source of ionizing radiation (usually approximately 0.2 milligram or approximately 0.9 microcurie of Americium-241) to detect smoke. This is an alpha particle emitter so it has large interaction cross sections with smoke particles in the air. This type of smoke detector is very common because it is inexpensive and better at detecting the smaller amounts of smoke produced by flaming fires. The ionization chamber consists of two plates connected to a battery. The alpha particles ionize the air between the plates, generating a small current. When smoke enters the chamber, the smoke particles attach to the ions in the chamber and the current is disrupted. The detector electronics sense the current change and sets off an alarm.

A photoelectric approach can be used to sense smoke by using the light scattered from the smoke particles. However, this approach is not sensitive to low levels of smoke as the ionization smoke detector.

4.0 CONCLUSIONS

Based on this state-of-the-art review and testing of ultrasonic imaging cameras, the following conclusions can be reached.

(1) Radiographic inspection can provide a clear, almost optical quality image of defects in the internal volume of a test sample with high resolution. There are a number of issues associated with using radiography as listed below:

- Radiography requires a “safe zone” be established during the taking of the radiograph.
- Film used with radiography requires chemical processing and these chemicals constitute hazardous waste.
- Processing time is on the order of 20 minutes.
- Radiography requires access to both sides of the part under test.
- Exposure times are usually on the order of at least 12 to 30 minutes (depending on the part thickness).
- Realtime imaging systems are available so that information can be obtained quickly, but the realtime image quality is less than that of film.
- Film provides a permanent archive of information about the quality of the part, but radiographic sources can easily be lost or misplaced.

(2) Ultrasonic inspection provides information about the internal quality of a part, but the information is provided on a time-and-amplitude plot and is not easily understood.

(3) A recent development, which combines ultrasonics and digital visual imaging, has provided a means to obtain a visual image based upon ultrasonic versus light waves. This technology is designated as ultrasonic imaging camera technology. This technology has greatly improved in the last few years, but the quality of the image is clearly not as good as the radiographic image. Some characteristics of this technology are as follows:

- Access to only one side of the part under inspection is required, however, contact and ultrasonic coupling with the part under inspection is required.
- No chemicals are associated with obtaining the image.
- Information is obtained in real time.
- Only a small image size is presently available, so it is difficult to generate a good archive of a large area.

(4) Ultrasonic imaging is the best technology for detecting debonds and in-plane defects (these are not detected by radiography).

(5) At the present time, more work is needed to make the ultrasonic imaging camera practical for angle-beam inspection.

(6) Ultrasonic sources can be used for other applications where isotope sources are often used, such as taking wall thickness measurement; however a contact couplant is often required and this approach cannot be easily used on parts that are at high temperature. Air-coupled transducers can be used now to detect delaminations and laminar defects in material and components without touching the part if access to both sides is possible even at high temperature. This capability cannot be duplicated by radiography.

(7) Advancements in air-coupled transducer technology are being made to the point where using it for gauging will be possible in the near future.

One of the major applications for the ultrasonic camera has been in the medical area. According to the Imperium, Inc., website, “Imperium, Inc with its clinical partners and advisory boards is under development on a full line of medical imaging products for clinical use with Digital Acoustic Video™, or DAV™. Our suite of Acoustocam™ imaging cameras* is focused on both imaging applications that current B-scan systems perform as well as expanded clinical uses that current ultrasound cannot satisfy. Images no longer exhibit unwanted speckle typically seen by conventional ultrasound images. Traditionally, B-scan ultrasound systems produce images which are perpendicular to the skin surface. Imperium's C-scan systems generate images which are parallel to the surface of the skin and records 2D plane images at different depths.”

“The patented technology is an ultrasound camera technology, basically a camcorder for ultrasound.”

Table 7 compares and contrasts DAV™ with other imaging modalities.

Table 7. Comparisons and Contrasts of DAV™ with Other Imaging Modalities

		B-scan Ultrasound	**X-ray**	**MRI**	**CT**
Cost	Less than 90K	200K-300K	100K-500K	Over 500K	Over 500K
Soft Tissue Imaging	Yes	Yes	No	Yes	No
Ionizing Radiation	No	No	Yes	No	Yes
Real-time Video Output	Yes	Yes	No	No	No
Spatial Resolution	0.5 mm	2-4 mm	3 mm	5 mm	5 mm
Speckle Artifacts	No	Yes	N/A	N/A	N/A

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(4) D.W. Schindel and D.A. Hutchins, "Through-thickness characterization of solids by wideband air-coupled ultrasound," Ultrasonics, 33(1), pp.11-17, 1995.

(5) Level III Study Guide, Radiographic Method, published by the American Society for Nondestructive Testing, Columbus, OH 43228.

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(1) “Two Dimensional Transducer Integrated Circuit,” Lasser, et.al. US Patent # 5,483,963.

(2) “Ultrasonic Imager,” Lasser, et. al. US Patent # 6,552,841.