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# EVALUATION OF X-RAY TECHNOLOGIES FOR USE IN THE MILITARY MUNITIONS RESPONSE PROGRAM

Prepared by
U.S. Army Engineering & Support Center, Huntsville

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US Army Corps of Engineers®

**EVALUATION OF X-RAY TECHNOLOGIES FOR USE IN THE MILITARY MUNITIONS RESPONSE PROGRAM**

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# 1.0 INTRODUCTION

## *1.1 BACKGROUND*

The U.S. Army Engineering Support Center, Hunstville (USAESCH) in support of the Military Munitions Response Program (MMRP) evaluated the use of X-ray equipment for field operations. In order to reduce the risk from Munitions & Explosives of Concern (MEC) and save time and money during field operations, X-ray equipment could be used to determine whether found MPPEH (Material Potentially Presenting an Explosive Hazard) actually contain explosive elements and pose a risk or whether they are inert.

## *1.2 AUTHORITY*

These X-ray evaluations were conducted under the auspices of the U.S. Army Engineering and Support Center's Military Munitions Response Program Innovative Technology Program.

## *1.3 OBJECTIVE*

The objective of these evaluations was to assess the capabilities of X-ray technology and determine if they were practical for field use. Specifically the various X-Ray equipment was evaluated for ease of use, set up time, useable features, software, durability, and if it had enough power to determine if MPPEH contained energetic/chemical filler or an armed fuze.

## *1.4 CONCLUSION*

After the evaluations it was determined that X-ray technology could be used to determine if an item of concern contained energetic/chemical filler or an armed fuze. Some of the equipment evaluated had more usable features and was better suited for field use. The results of these evaluation are listed in section 4.

# 2.0 X-RAY EQIPMENT

## *1. Vendor: CMOS / Envision Product Design*

**System: EnvisionScan / Envision 4x4**
**Manufacturer: Envision Product Design**
**Source: XR-200 / CP160**
**Test Date: 7/24/2008**

2. *Vendor: Delta X-ray*

   **System: foX-Rayzor**
   **Manufacturer: Vidisco**
   **Source: XR-200**
   **Test Date: 6/26/2008**

3. *Vendor: SAIC*

   **System: RTR-4N**
   **Manufacturer: SAIC**
   **Source: XR-200**
   **Test Date: 7/22/2008**

4. *Vendor: Scanna*

   **System: ScanTrak / ScanWedge and CR35 Portable Image Plate Scanner**
   **Manufacturer: Scanna**
   **Source: XRS-3, XR-200**
   **Test Date: 6/13/2008; 2/19/2009**

# 3.0 EVALUATION PROCEDURES

Four companies participated in the X-ray evaluations, and representatives from each brought a variety of X-ray equipment. All equipment demonstrations were performed inside a warehouse on metal objects provided by USAESCH. The following inert items were provided for X-ray evaluations: 2.36” rocket, 3” Stokes mortar, BLU 26 submunition, 105mm projectile, 90mm projectile, 75mm projectile, 81mm mortar, 3.5” rocket and a K951/952 kit (commonly referred to as a “Pig”) containing inert Chemical Agent Identification Set (CAIS) vials.

Vendors were expected to demonstrate the usefulness of the equipment to support USAESCH field operations. Of particular interest during these evaluations were the ease of use in the field, portability, ability of equipment to image intended targets, penetration capability, setup time required, and safety of operation. Each vendor was provided access to the same site and items for evaluation. All of the systems evaluated had both wireless and hard wire operating modes, and the option of different sources and intensifying screens. Additionally, all vendors used the XR200 X-ray source, except for the initial Scanna test using the XRS-3 and CMOS who switched to the CP-160 after having battery problems with their other source. Each vendor was allowed to complete demonstration of as many X-ray systems as they wished.

Representatives from USAESCH involved with the X-ray testing varied with each evaluation. However there were two representatives who were present for all tests, Kelly Enriquez and Walt Zange. Mr. Zange has extensive Explosives Ordnance Disposal

(EOD) military experience and was the expert for determining usefulness of X-ray equipment for fieldwork. During each test, comment sheets were submitted by USAESCH representatives, which have been collated in APPENDIX B.

# 4.0 RESULTS

See Table 1 for a comparison of system features, APPENDIX A for comparison of images from the four vendors, and APPENDIX B for test comments.

## *4.1 CMOS / Envision Product Design*

Two representatives from CMOS came to demonstrate their X-ray systems on July 24th. System setup took approximately 15 minutes. However, the large imaging screen initially used took over 15 minutes to calibrate. Even after calibration, the contrasting of each panel that composed the larger screen did not create an even background. They began tests using the XR-200 source. The pulse settings on the XR-200 had to be adjusted manually, which would be cumbersome during field operations. Eventually they switched to the "CP-160" constant potential X-ray source and Envision 4x4 screen for the remainder of the demo. Software used by CMOS seemed to be slow and not as robust as other X-ray imaging software. The vendor brought another software package that was said to have more functionality. However, he was unfamiliar with the software and unable to demonstrate any additional features. The CMOS system worked well for thinner items, but failed to penetrate larger items (e.g. 75mm projectile). The CMOS vendor provided USAESCH additional images (Fig. C-2) from the Idaho National Engineering Lab (INEL) using a better CMOS/Envision imaging system. However, the vendor did not bring that higher-resolution system to the Huntsville evaluation. See APPENDIX C for all X-ray images provided by CMOS.

***Figure 1 Envision 4x4 X-ray System***

## *4.2 DELTA X-RAY*

Delta X-ray demonstrated their system on June 26th. There were two representatives from Delta X-ray and one from Vidisco, the system manufacturer. The primary system shown

was the Vidisco foX-Rayzor with the XR-200 source. Several other Vidisco systems were brought and discussed, however the evaluations proceeded with the foX-Rayzor as that seemed to be their best imager. The demonstrators fully explained setup and software operation, with setup time taking about 10-15 minutes. The imaging software seemed to be extremely user-friendly and robust. Along with the imagery, the software creates a database to encapsulate additional information about imaged targets. The software is proprietary, but allows for images to be saved in a variety of open formats (e.g. TIFF, JPEG) along with metadata as ASCII files. Additional software features included stitching images together and estimating target thickness by contrasting two images. Vidisco systems also have the ability to filter dual-frequency images in order to determine organic content. Out of all the systems evaluated, the images from Delta X-ray were the most consistently usable and the software had the most features. See APPENDIX D for all images provided by Delta X-ray.

***Figure 2 Vidisco's foX-Rayzor***

## *4.3 SAIC*

On July 22nd, a representative from SAIC came to the Huntsville warehouse to demonstrate their RTR-4N X-ray system with an XR-200 source. The vendor setup the system in about 15 minutes then spent between 15 and 20 minutes calibrating the large imaging screen. During the demonstration, the vendor had to replace the source battery twice due to the batteries not being fully charged, so we were unable to estimate the battery life. Towards the end of the evaluation the X-ray source required several minute breaks in between images, possibly due to overheating. It would be expected that all systems using the XR-200 source could encounter similar problems, however during these evaluations SAIC was the only vendor that had this problem. The software used with the RTR-4N system was not as user-friendly as other systems evaluated and was unable to save contrasted images. See APPENDIX E for all test images provided by SAIC.

***Figure 3 SAIC RTR-4 System Components***

## *4.4 SCANNA*

The initial Scanna X-ray demonstration occurred on June 13, 2008 in Huntsville. The system evaluated was the SCANWEDGE portable flat panel digital X-ray system with an XRS-3 source. A second, "better resolution" imaging screen was also brought for evaluation, however the demonstrator could not get that system's laptop computer working, and therefore that screen was not evaluated. Overall ease of setup was good on this system, as the system was ready for demonstrations within 15 minutes. Imaging was also fast and the software seemed very user-friendly. Image contrasting capability existed using the native software format, and could also produce static JPEG or Bitmap images. The Scanna software allows for accumulation of multiple pulses to one image. Battery life on the system lasted for about one and a half to two hours, which is the total time during which the first evaluations took place.

**Figure 4** ***SCANNA ScanWedge System***

Two Scanna representatives returned to demonstrate an additional system on February 19, 2009. The system demonstrated was the CR35 Portable Image Plate Scanner, which was the only system evaluated that used a flexible image plate and scanner. While the imaging resolution was better than their previously tested Scanna system, the CR35 seemed less field-worthy. Because the system is not digital, it requires the user to take the image, pick up and scan the film before determining if the image was useful. This process could result in multiple iterations back and forth to the MPPEH before a useful image is

obtained. Otherwise, this system seemed user-friendly and was able to produce good images of several of the test items.

## *4.5 SUMMARY*

Overall, the X-ray evaluations went well. It was apparent with all evaluated systems that X-ray technology could be used in the field to determine if certain items contain energetic/chemical filler or an armed fuze. Each vendor had systems with some penetration capability into the thinner items evaluated (e.g. 2.36" rocket). There was much variability in evaluating thicker items (e.g. 81mm mortar), with Delta X-Ray producing more consistently detailed images than other systems evaluated.

Field readiness was a major factor during these X-ray evaluations. Each vendor had X-ray systems that were contained in ruggedized cases. At least one system also had the capability of carrying X-ray equipment via a customized backpack. All systems had the option of wireless data/signal transmission. Of all the systems evaluated, the CMOS X-ray was least field-worthy due to the system's inability to penetrate many of the objects evaluated and the need for manually adjusting pulse rates with the XR-200 source. Each system had a thin imaging screen; except for SAIC's RTR-4N whose screen is 7 inches deep. Thinner screens would likely be more useful in the field, as it would require a smaller area to be cleared around the item being imaged.

Battery life is a significant factor to consider for field use of X-ray equipment. SAIC had problems with their batteries either not being fully charged or being faulty and had to replace their battery twice during the evaluation period. The battery during the first Scanna evaluation lasted for less than two hours of usage.

Safety of operation issues were fairly consistent with each system and depended on the X-ray source used. Most of the systems use Golden Engineering's XR-200 source which has a standoff distance ranging from 24 to 30 meters in front of the source, and 3 to 6 meters behind the source. CMOS's constant potential source has a stand-off range similar to the XR-200 source (Table 1).

***Table 1 Comparison of Features from Tested Systems***

| System | Imaging Screen | Battery Life | Standoff Distance | Field Readiness |
|---|---|---|---|---|
| **Scanna Scanwedge** | Scanwedge 2520 - 8"x10"<br>ScanWedge 3325 - 10"x13"<br>582 x 752 pixels | 4000 pulses (less than 2 hours as tested) | Approximately 24m in front / 3m behind | Ruggedized case contains: source, screen, cable, spare battery & charger |
| **Scanna CR35 Portable Image Plate Scanner** | Variable plate sizes up to approximately 14"x18" | Similar to other XR-200 sources tested (2 hrs or less) | Approximately 24m in front / 3m behind | Imaging screen has to be protected from scratching. Multiple iterations may be necessary to obtain a good image. There is no |

| | | | | |
|---|---|---|---|---|
| | | | | automated image transfer to computer. |
| **Delta X-ray foX-Rayzor** | 8.75”x8.75” imaging size, 14.2”x13”x0.5” outside dimensions, 14 bit dynamic range | “Over 2hr operation on rechargeable smart Lithium Ion batteries”; about 4000 pulses | Within concrete walls 10ft / With no shielding 100ft | Rugged pelican case: 13.9”x24.5”x19.4”, 66lbs; equipment can also be carried via 65lb backpack |
| **SAIC RTR-4N** | 8”x10.7” imaging size, 11.75”x13.25”x7.0” outside dimensions | Rechargeable nickel-cadmium battery, spare & charger; problems with battery charge during test, pulses per battery life not provided | Typical exclusion zone 30m in front / 6m behind | Ruggedized case: 31”x11.5”x20”, 26lbs |
| **CMOS CP160 / Envision 4x4** | 4”x4” imaging size, 8.5”x7.25”x1.25” outside dimensions, 12 bit dynamic range | Not provided | Without any shielding 20m in front of the source, 5m away from beam | Software Manual electronic copy only; ruggedized case but does not include source; screen is made from metal & is resistant to breaking |

## *4.6 RECOMMENDATIONS*

Some of the equipment tested had outstanding capabilities and met all of the objectives stated in paragraph 1.3. The X-Ray technology that is available has the potential to decrease project cost while enhancing safety to site personnel on projects with mass MEC contamination, or possible CWM. It is recommended that these systems be placed into field use at appropriate projects.

# APPENDIX A: IMAGE TEST RESULTS

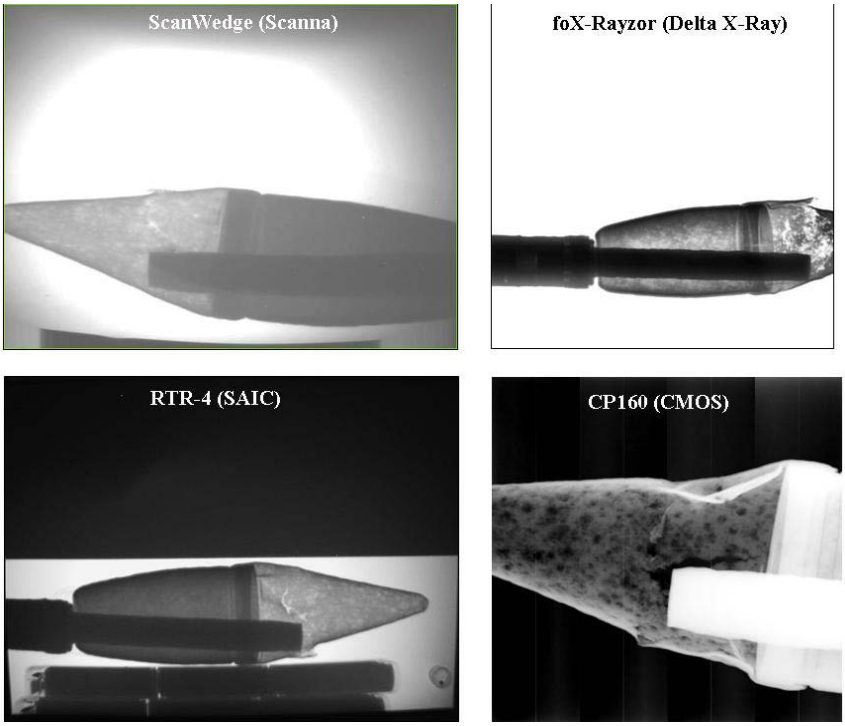



***Figure A-1 Test results for 2.36" Rocket***

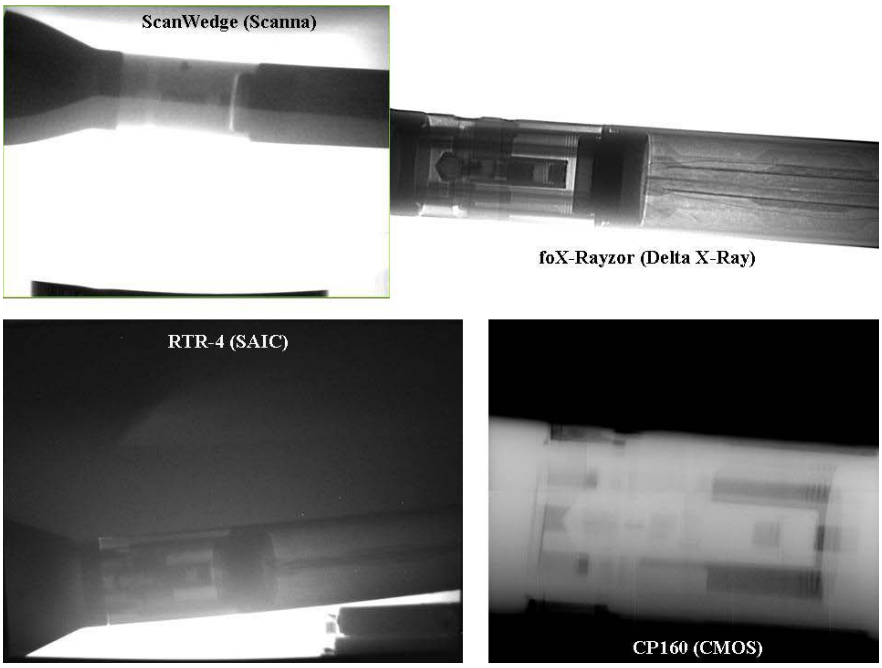



***Figure A-2 Test results for 3.5" Rocket***

# APPENDIX B: TEST COMMENTS

| CMOS | COMMENTS |
|---|---|
| Initial Setup | "Comes in a very large durable hard case. Set up time EST 15 min. This system was controlled by power output, not pulses."<br>"Initially showed us the Openvision LT system - extremely easy setup & use, but not much penetration of ordnance. CP160 was also easy set-up. Longest time was spent on software settings / calibration." |
| Field Usability | "Standard laptop. Ruggedized cases. Envision screen is metal rather than glass, so it's very field-worthy. XR200 source had a manual pulse setting, which is very inconvenient. The software was slower in acquiring images than other systems tested. Constant potential source is larger than XR200, not sure how easy it would be to use in field."<br>"This X-Ray system is not practical for the UXO field. They brought three different systems with them. All three systems were too weak to penetrate all the targets. One system could barely penetrate a 2.36" rocket. Another system required the operator to manually enter pulse numbers (this is more time on target and a lot more time consuming). The third system (the one tested) was weak and cumbersome. Of the four vendors reviewed this company had the weakest system. Screen was too small. The program does not offer stitching X-Rays together or transpose X-Rays to determine item thickness." |
| General Comments | "Vendor attempted to show an upgraded version of the software with more functionality, but did not know the buttonology to showcase it. Vendor said they had another system that probably would have worked with the thicker items, but they didn't bring it because he didn't know what to expect. They also have an 8" x 12" panel that is almost ready." |
| Test Items | 2.36" Rocket: "10 inch stand off. X-ray clearly showed the ballast rod."<br>3" Stokes Mortar: "Could see water line and buster tube."<br>BLU 26 Submunition: "Could barely penetrate."<br>PIG w/ CAIS: "Could see water lines in the vials"<br>M51 Fuze: "Good picture, could see no firing pin was present."<br>105mm Projectile: "X-Ray was not able to obtain a picture." |

| Delta X-Ray | COMMENTS |
|---|---|
| Initial Setup | "9" square imaging, very thin. Easy set-up, can be wireless. One computer, can be a toughbook"<br>"Comes in a good durable hard case. Set up can be both hard wire or RF. Comes with three intensifying screens and a backpack. Set up time EST 10 min." |
| Field Usability | "The X-ray was very effective, results were great. The program had many more usable features that previous X-ray did not. For example stitching together of several X-Rays of the same item, transposing one X-ray on top of another to determine thickness of the item, organic X-Ray, and zoom to 800X. Intensifying screen was thin enough so a large hole would not have to be dug to perform an X-ray on a buried suspected live item. System set was easy and took about 10 min. X-ray battery life is about 4000 pulses on a full charge."<br>"65 lb backpack or hard case w/ wheels. Battery life is about 4000 pulses (we tested for 2+ hours with no problem). Panasonic toughbook available for more ruggedized HW. Case/pack has 50m cable. Software easy to use w/ one button for histogram equalization (quick contrast for image), software has warning bell when X-ray is in use (can be turned off)." |
| General | "Contractors were very well prepared & extremely knowledgeable about the system. |

| | |
|---|---|
| Comments | Test was a vast improvement over Scanna & images were much better quality. Imagery is higher bit (high grayscale) and is about 6MB per image. Database created with software to attach additional information to each image. Software is proprietary, but images can be saved in TIFF, JPG, or BMP and metadata can be saved as ASCII TXT.”<br>“Company and their demonstrators were very professional. They took the time to explain all their equipment and they provided brochures on their equipment.” |
| Test Items | 2.36” Rocket “20 Pulses and 10 inch stand off. X-ray clearly showed the ballast rod.”<br>3” Stokes: “60 pulses 10 inch stand off could see water line and buster tube.”<br>81mm Mortar, 105mm & 90mm Projectiles: “Demonstrator placed a lead object behind all three items to demonstrate the X-Ray could penetrate the items. The X-ray was successful.”<br>BLU 26 Submunition “70 pluses 8 inch stand off could see through the item. If there was HE or a fuze present I’m confident the X-ray would have detected it.”<br>PIG w/ CAIS: “Great picture could clearly see vials and liquid.” |

| SAIC | COMMENTS |
|---|---|
| Initial Setup | “Comes in a very large durable hard case. Set up can be both hard wire or RF. Comes with two intensifying screens. Set up time EST 15 min.”<br>“Set up took awhile…no explanation from vendor on how to. He had to calibrate the large screen that we used first, which took 15+ minutes. Later when we switched to the smaller screen, that took several minutes too.” |
| Field Usability | “Large ruggedized case, standard (non ruggedized) laptop, large screen fits in padded carrier case with shoulder strap. Source overheated and/or was having problems with the repeat shots towards the end, batteries weren't fully charged or were having problems holding a charge”<br>“This X-Ray system/company is not practical for the UXO field. The equipment is cumbersome. The screens are too thick. If the item being X-Rayed is subsurface or located close to a tree this system would not be able to do the job. X-Rays done with the larger screen were fuzzy and unclear. And all the other X-Rays required a lead shield for a better picture. The program this system operates off of is not user friendly. It is not possible to save modified images; stitch X-Rays together or transpose X-Rays to determine item thickness.” |
| General Comments | “Demonstrator was not familiar with equipment, never explained capabilities, and showed up unprepared. Two of the three batteries were not charged and the other battery had ½ charge. Demonstrator was not able to answer simple questions about his equipment, such as how many pulse can the system get from a full battery charge.”<br>“Can't save contrasted images with their software. Large image screen has 4 imagers that don't always match contrast to each other.” |
| Test Items | 2.36” Rocket: “10 Pulses and 28 inch stand off. X-ray clearly showed the ballast rod.”<br>3” Stokes: “40 pulses 28 inch stand off could see water line and buster tube.”<br>BLU 26 Submunition: “80 pluses 18 inch stand off could see through the item. If there was HE or a fuze present I’m confident the X-ray would have detected it.”<br>PIG w/ CAIS: “There was about 15 attempts to X-Ray this item. Two different screens were used. Using the smaller screen, 188 pulses and the item sitting vertical a usable X-Ray was achieved.”<br>3.5” Rocket: “60 pulses 20 inch standoff could see there was no firing pin in the fuze.”<br>105mm Projectile: “X-Ray was not able to obtain a picture.” |

| SCANNA | COMMENTS (ScanWedge) |
|---|---|
| Initial Setup | "Comes in a good durable hard case. Set up can be both hard wire or RF. Comes with two intensifying screens. (One computer was not working was not able to see the stronger screen in action.) Set up time EST 15 min."<br>"4000 pulses for a new battery, charge while in case, invert DC adaptor for car, can be run from main power, 100 meters max cable distance, RF (wireless), Computer boot up takes longer than other equipment setup"<br>"Computer problem w/ 1 system so we couldn't test the screen with better resolution. Otherwise, the system is easy to set up & fast. 2 different software systems for 2 screens" |
| Field Usability | "Large, ruggedized case, small wheels 2 laptops non-ruggedized inside, good repeatability for about 1.5 - 2 hours (when screen battery died)"<br>"Contrast can be adjusted real time, shows negative, Pulse accumulative on the same digital file. Once firing starts you can not stop. Save."<br>"The X-ray didn't underachieve or produce any spectacular results. Very predictable results/capabilities for an X-ray of this size. Intensifying screen was thin enough so a large hole would not have to be dug to perform an X-ray on a buried suspected live item. System set up was easy and took about 15 min. X-ray battery life is about 2000 pulses on a full charge." |
| General Comments | "X-ray equipment arrived late demonstration did not start until 1130. Demonstrator did not explain X-ray setup, capabilities, or system/program requirements. He did not state if the computer came with the X-ray kit. This company had a lackadaisical attitude towards the preparation and the demonstration of their equipment to a potential customer. How would their attitude and service be once their item was purchased."<br>"Quick imaging time Proprietary software format for adjusting image contrast or can be saved as static jpg/bmp" |
| Test Items | 2.36" Rocket: "30 Pulses and 20 inch stand off. Xray clearly showed the ballast rod."<br>3" Stokes: "75 pulses 10 inch stand off could see water line and buster tube."<br>BLU 26 Submunition: "60 pluses 8 inch stand off could see through the item. If there was HE or a fuze present I'm confident the X-ray would have detected it."<br>PIG w/ CAIS: "Could barely see glass vials, but could not see if liquid was in the vials."<br>3.5" Rocket: "40 pulses 20 inch standoff could see there was no firing pin in the fuze." |

| SCANNA | COMMENTS (CR35 Portable Image Plate Scanner) |
|---|---|
| Initial Setup | "Setup is fairly quick and straight-forward." |
| Field Usability | "Plates need to be scanned, means someone has to run out to test site & grab the plate then scan it in before knowing whether the image is any good (not digital). The film can get scratched/dirty and affect image quality. One plate can normally take 4000 shots. Scan X is bulky, but can come in a ruggedized case. Scanner can be converted to run off car battery. Doesn't seem as practical for field use as digital systems."<br>"This X-ray system would not be practical for UXO field use. It requires the user to manually enter the required pulses (Time on Target). Each x-ray must be developed by the processor, this takes too much time. The screen is susceptible to sun light, is very delicate, and expensive to replace (about $800). The system did have some of the more desirable features but didn't have the power to penetrate the thicker items." |
| General Comments | "SW has stitching capability (same SW as before). Takes a few minutes to take and process a shot. Rollers of scanner can get dirty and add lines to the image" |
| Test Items | 2.36" Rocket: "X-ray clearly showed the ballast rod."<br>3" Stokes: "could see water line and buster tube."<br>BLU 26 Submunition: "If there was HE or a fuze present I'm confident the X-ray |

| | |
|---|---|
| | would have detected it."<br>PIG w/ CAIS: "not a good readable image." |

# APPENDIX C: CMOS X-RAY IMAGES

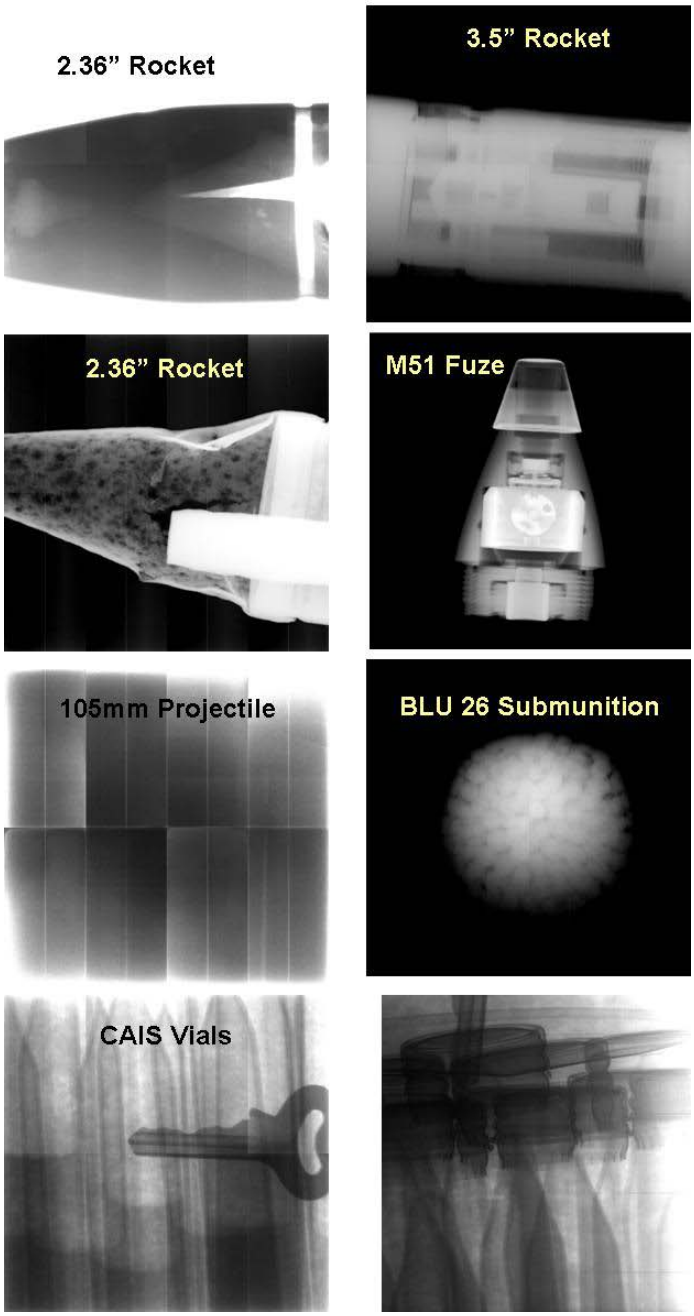



***Figure C-1 Huntsville test results from CMOS***

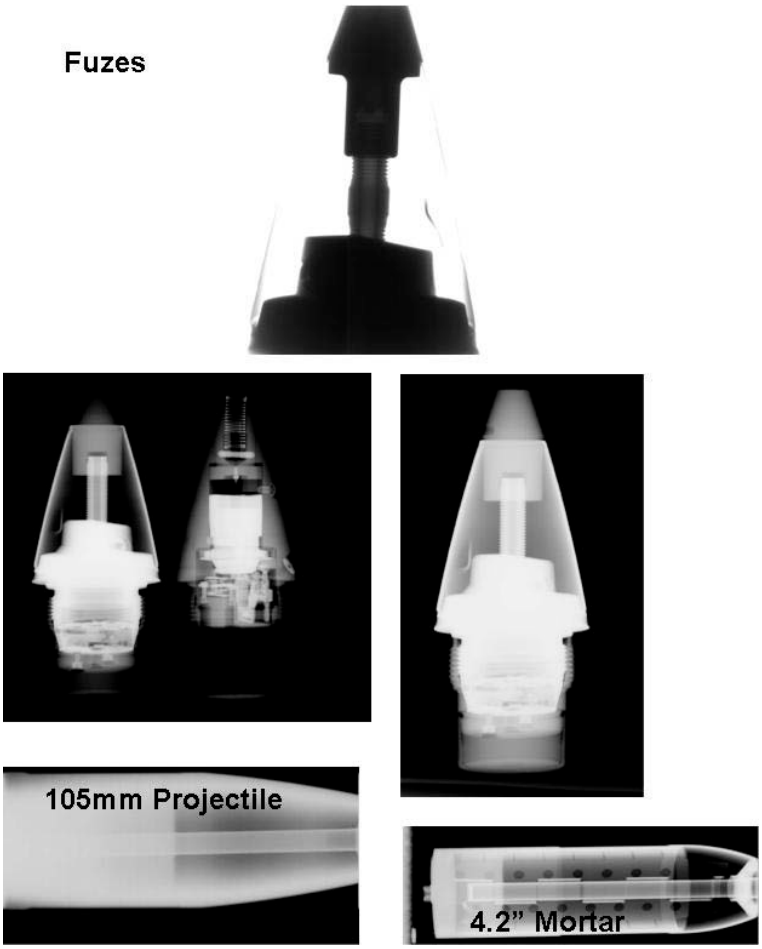



*Figure C-2 INEL test results from CMOS*

# APPENDIX D: DELTA X-RAY IMAGES

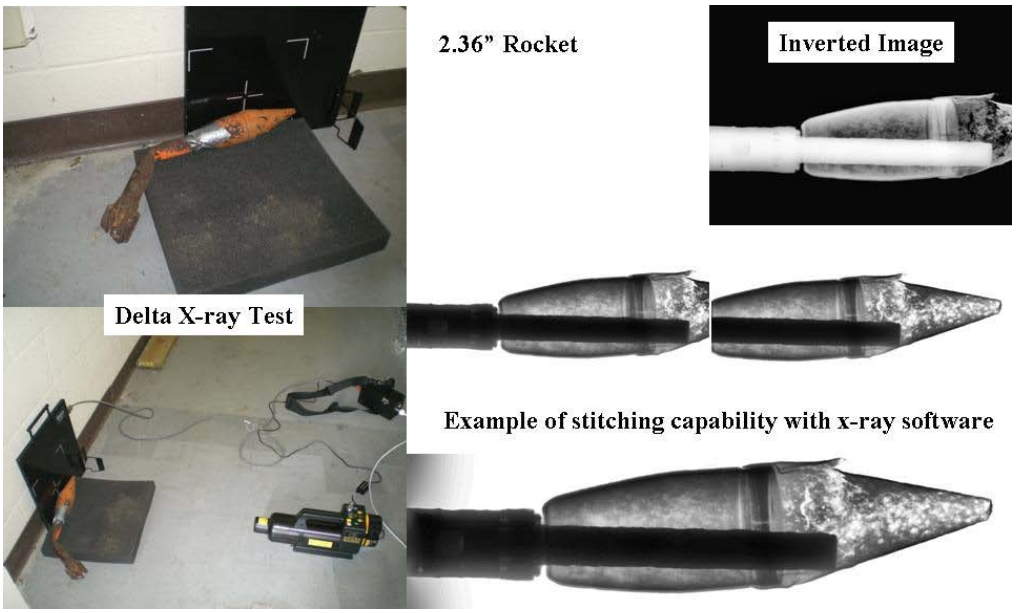



*Figure D-1 Delta X-ray test results for 2.36" Rocket*

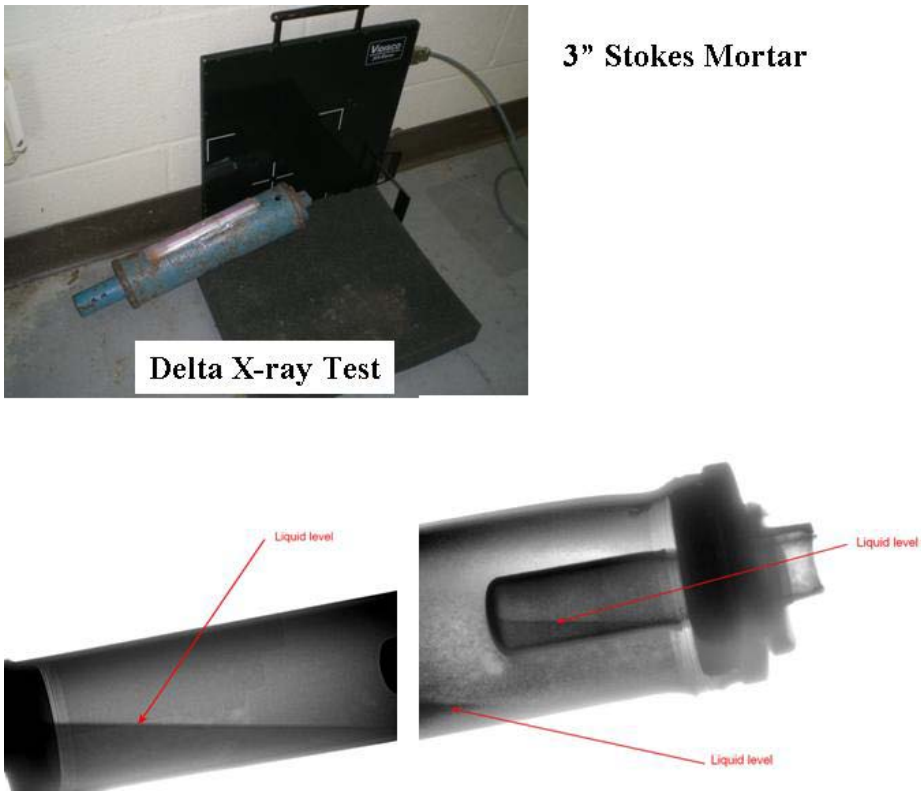
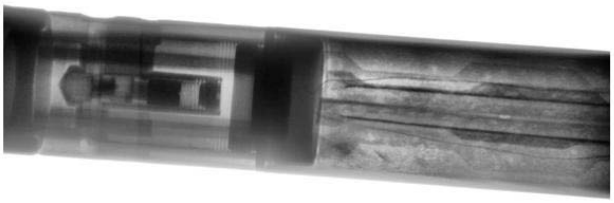
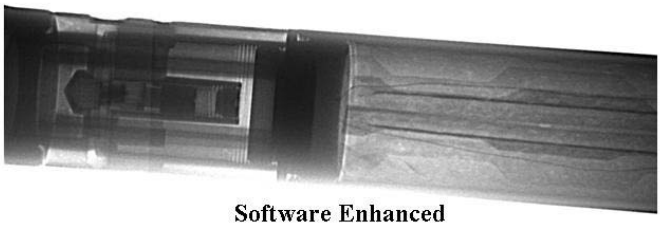



*Figure D-2 Delta X-ray test results for 3" Stokes Mortar*

**3.5" Rocket**





**Software Enhanced**

***Figure D-3 Delta X-ray test results for 3.5" Rocket***

**75mm Projectile**

***Figure D-4 Delta X-ray test results for 75mm Projectile***

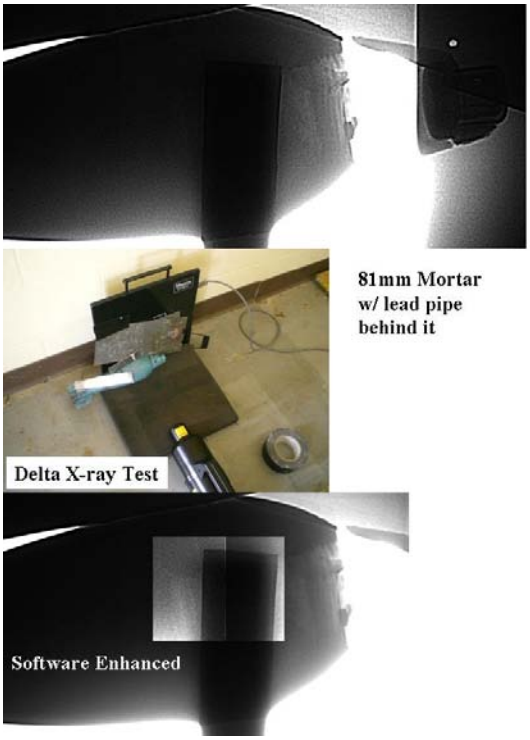



***Figure D-5 Delta X-ray test results for 81mm Mortar***

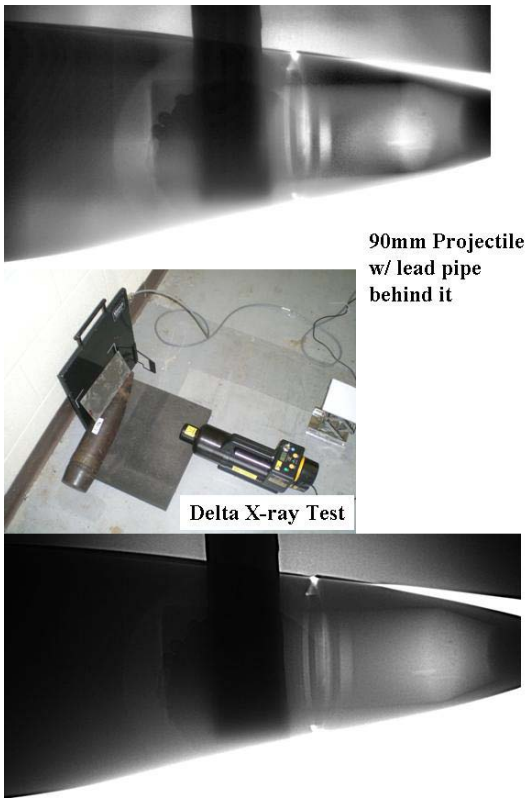



***Figure D-6 Delta X-ray test results for 90mm Projectile***

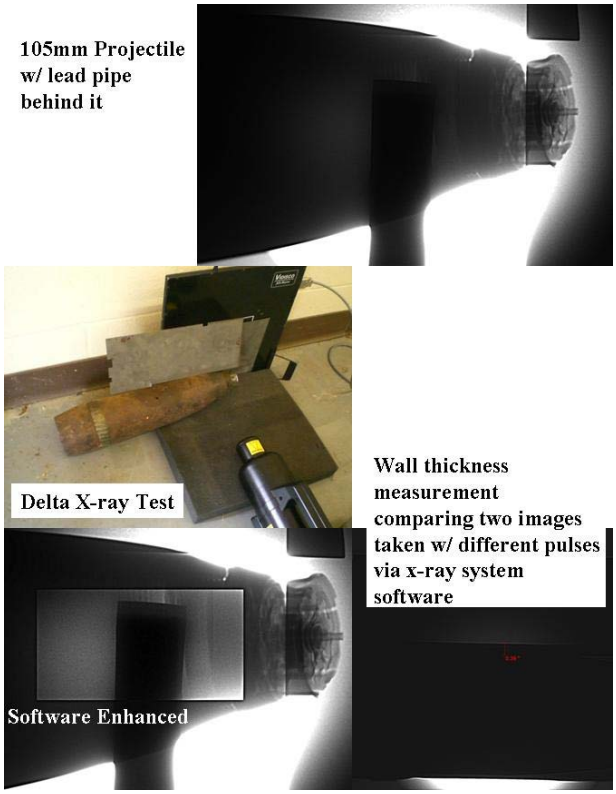



*Figure D-7 Delta X-ray test results for 105mm Projectile*

*Figure D-8 Delta X-ray test results for BLU 26 Submunition*

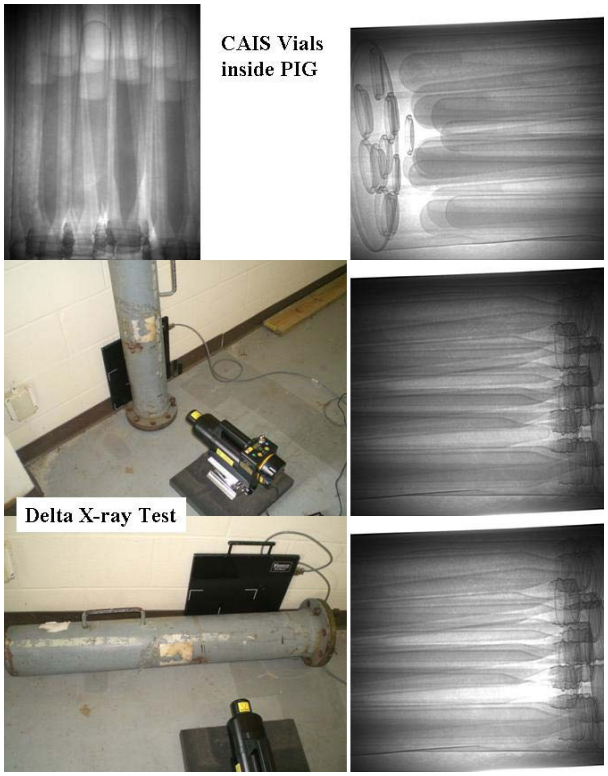
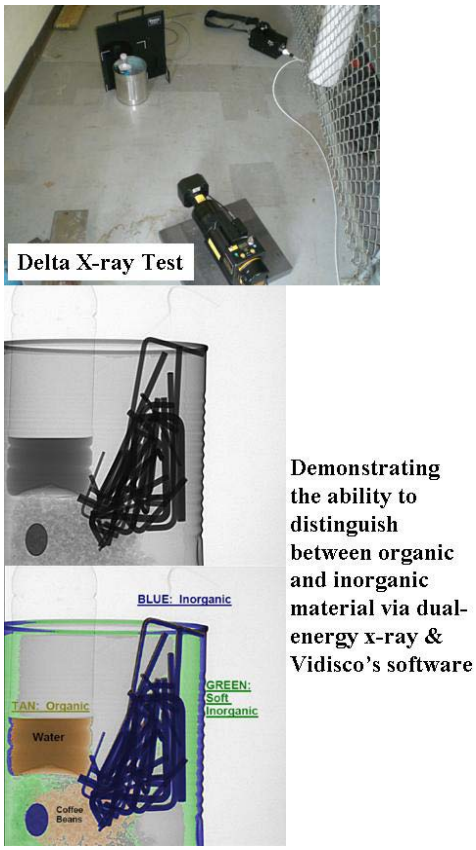



*Figure D-9 Delta X-ray test results for CAIS Vials*




**Demonstrating the ability to distinguish between organic and inorganic material via dual-energy x-ray & Vidisco's software**

*Figure D-10 Delta X-ray test results for Organic Material*

# APPENDIX E: SAIC X-RAY IMAGES

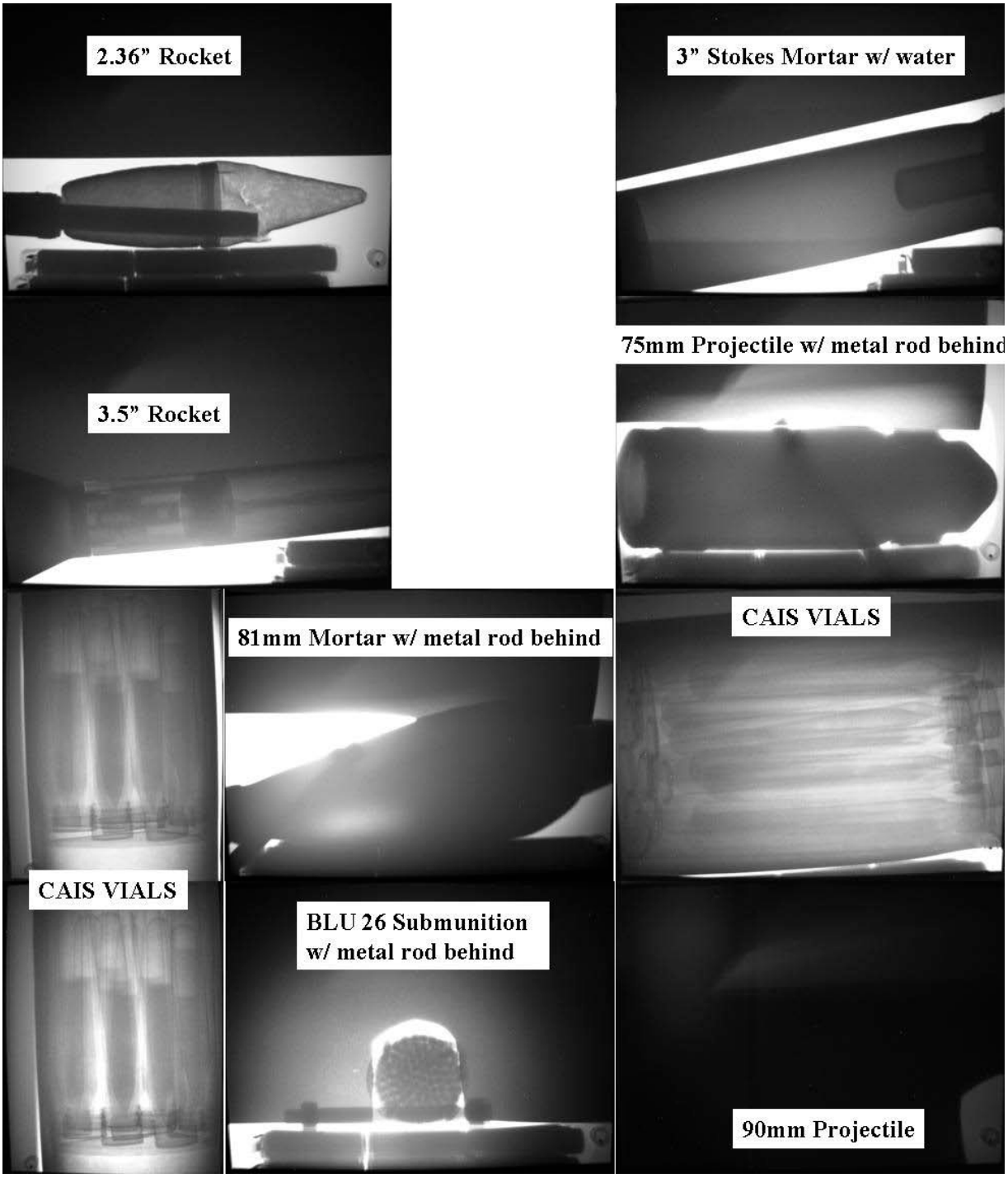



*Figure E-1 Huntsville test results from SAIC*

**APPENDIX F: SCANNA X-RAY IMAGES**

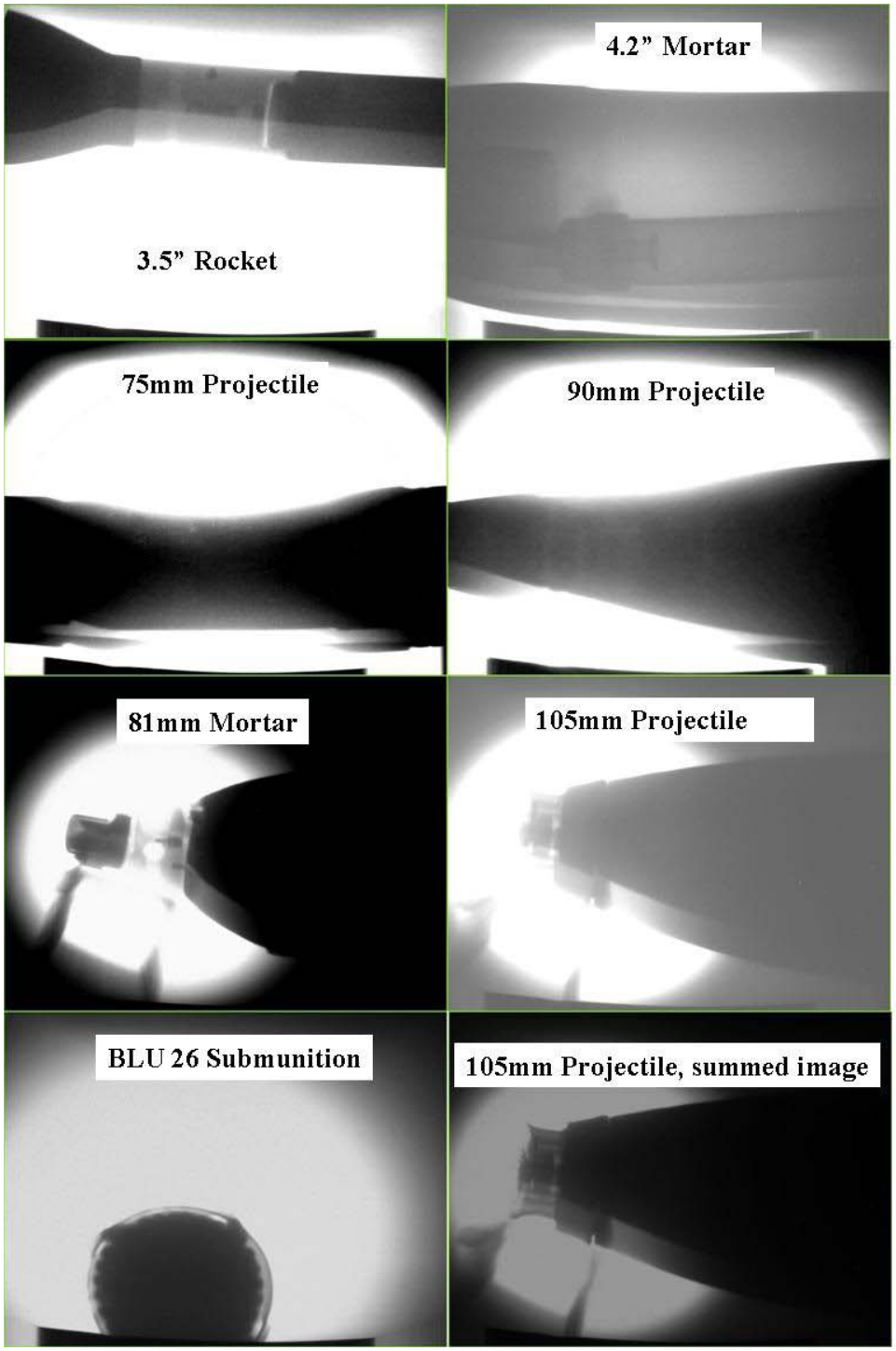



*Figure F-1 Huntsville test results from SCANNA ScanWedge*

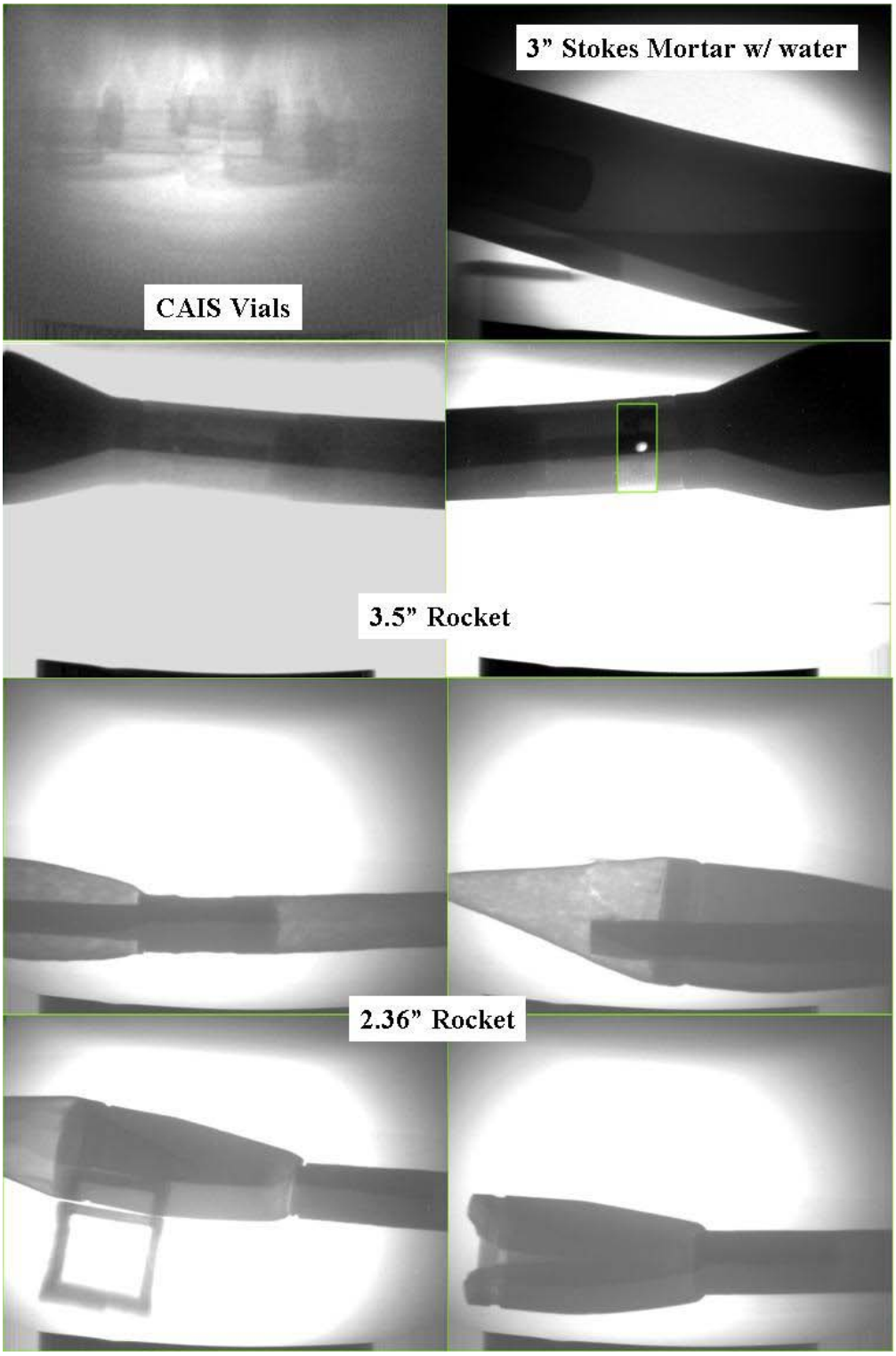



***Figure F-2 Huntsville test results from SCANNA ScanWedge continued***

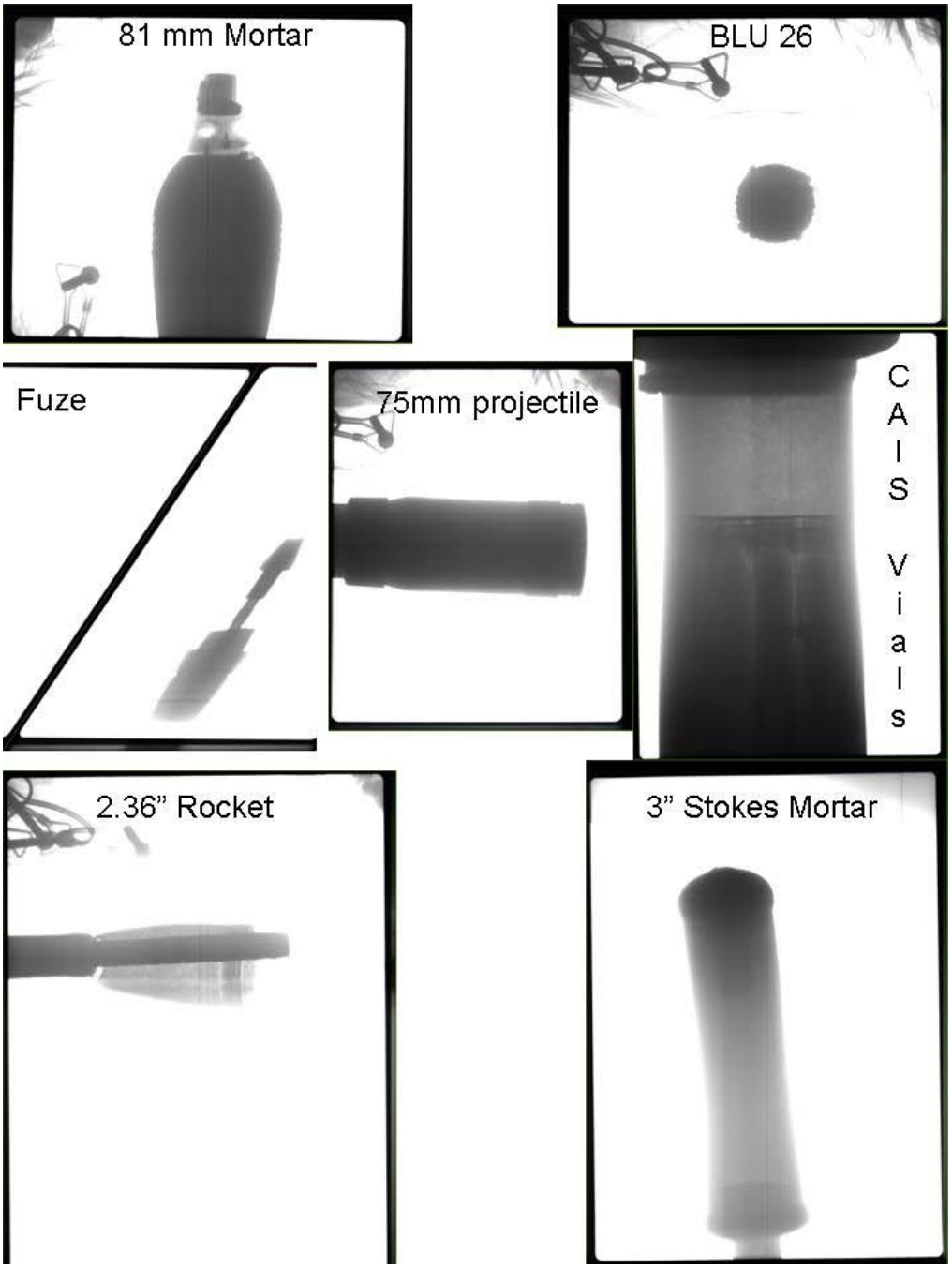



***Figure F-3 Huntsville test results from SCANNA CR35***