INL/EXT-10-20231

Digital Radiography and Computed Tomography (DRCT) Product Improvement Plan (PIP)

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Bob Pink
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December 2010

Idaho National Laboratory

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EXECUTIVE SUMMARY

Idaho National Laboratory (INL) has been developing and deploying x-ray inspection systems for chemical weapons containers for the past 12 years under the direction of the Project Manager for Non-Stockpile Chemical Materiel (PMNSCM). In fiscal year (FY)-10 funding was provided to advance the capabilities of these systems through the Digital Radiography and Computed Tomography (DRCT) Product Improvement Plan (PIP), funded by PMNSCM. DRCT PIP identified three research tasks: end user study, detector evaluation, and DRCT/PINS integration. Work commenced in February 2010.

Due to the late start and the schedule for field inspection of munitions at various sites, it was not possible to spend sufficient field time with operators to develop a complete end user study. We were able to interact with several operators, principally Mr. Mike Rowan, who provided substantial useful input through several discussions and development of a set of field notes from the Pueblo, CO field mission. Included in this report is what was learned from interacting with several interested groups including PMNSCM personnel and field operators. We will be pursuing ongoing interactions with field personnel as opportunities arise in FY-11.

The key accomplishments in FY-10 and proposed efforts for FY-11 are:

- Acquisition and initial study of an advanced x-ray detector

  After performing a study of available detectors, an off-the-shelf design from Detection Technologies (DT), Inc. was acquired for testing and demonstration. The detector has gone through preliminary testing for operability and image quality. Thus far it appears that the detector is superior to the detectors currently residing on the DRCT systems and the DRCT gantry can be adapted to accept a DT detector. The electronic and software interface needs further evaluation but no obvious insurmountable issues have been seen so far. It is planned for the detector to undergo additional testing, development, and integration onto a DRCT scanner in FY-11.

- Review and testing of commercial lower energy (below 450kVp) portable x-ray generators

  A survey was performed to determine if there is a more useful portable x-ray generator available for use with the DRCT scanners. Commercially available options were identified and a set of tests were performed to compare x-ray generator output. It was determined that, for the time being, the Yxlon Smart 300 HP portable x-ray generation system is still the optimum choice for the DRCT scanners. In FY-11 it is proposed to investigate much higher energy sources including megavolt sources such as betatrons and linacs and some recently announced x-ray generators that have the potential to operate at up to 800kVp.

- DRCT/Portable Isotopic Neutron Spectroscopy (PINS) efforts

  Several subtasks were initiated under this task. Conceptual design was initiated for a transport cart that would enable movement of an object from a storage point to the DRCT scanner, then to a PINS station. The cart would initially provide rotational motion for the object and could directly couple into the current DRCT gantry. Key information from the x-ray scan could be placed on the object via a mechanical tag (i.e., ink marking on the object) or an electronic tag (such as a radio-frequency identification [RFID] tag). Several options are being considered for this information transfer. Additionally, efforts were initiated to perform volume estimation calculations for liquids inside standard sizes of chemical munitions. All of these subtasks are proposed to be continued in FY-11.

A recent driver for the PIP work is the recognized need for improved imaging capability for large objects. The DRCT systems are presently optimized for (and limited to) providing complete images of objects smaller in steel thickness than 155 mm munitions. In order to enable the DRCT systems to provide images of larger diameter objects, improvements are needed in x-ray generation, x-ray detection, and image processing. An underlying theme in all efforts for 2011 will be to expand the capability of DRCT systems to improve image results for larger objects.

ACKNOWLEDGEMENTS

The authors would like to thank Mr. Mike Rowan and Mr. Stacey Barker for useful discussions and relevant input regarding the DRCT scanning systems. We would also like to thank Mr. Leonard Rowe for guidance and support.

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FIGURES

TABLES

ACRONYMS

CARA	CBRNE analytical and remediation activity
CBRNE	chemical, biological, radiological, nuclear and high-yield explosives
DT	Detection Technologies
DRCT	Digital Radiography and Computed Tomography
EEST	Energy and Environment Science and Technology
FOV	field of view
INL	Idaho National Laboratory
ICM	Industrial Control Machines Inc.
MMAS	Mobile Munitions Assessment Systems
MPT	multipage transponder
MS&E	Materials Science and Engineering
N&HS	National and Homeland Security
NSCM	Non-Stockpile Chemical Materiel
PBMAS	Pine Bluff Munitions Assessment System
PCD	Pueblo Chemical Depot
PINS	Portable Isotopic Neutron Spectroscopy
PIP	product improvement plan
PMNSCM	Project Manager for Non-Stockpile Chemical Materiel
R&D	research and development
RFID	radio-frequency identification
RNC	Rad/Nuc/CBRNE
R/W	read/write
S&T	Science and Technology
TI	Texas Instrument

Digital Radiography and Computed Tomography (DRCT) Product Improvement Plan (PIP)

1. INTRODUCTION

Idaho National Laboratory (INL) has been developing and deploying x-ray inspection systems for chemical weapons containers since 1998 under the direction of the Project Manager for Non-Stockpile Chemical Materiel (PMNSCM). In fiscal year (FY)-10 funding was provided to advance the capabilities of these systems through the DRCT (Digital Radiography and Computed Tomography) Product Improvement Plan (PIP). The DRCT PIP identified three research tasks: end user study, detector evaluation, and DRCT/PINS integration. There was also a project management task. The guiding statement of work is provided as Appendix A in this report. Work commenced in February 2010. This report provides status for each of the three tasks.

1.1 Relevant INL Interdepartmental Relationships

The DRCT development group resides primarily within the Materials Science and Engineering (MS&E) Department at INL. MS&E resides within the Science and Technology (S&T) Division of the Energy and Environment Science and Technology (EEST) Directorate at INL. The DRCT group works closely with the MMAS (Mobile Munitions Assessment Systems) group headed by Stacey Barker and the PINS (Portable Isotopic Neutron Spectroscopy) group headed by Dr. Gus Caffrey. Both of these groups reside within the Rad/Nuc/CBRNE (RNC) Department. The RNC Department resides within the Nuclear Nonproliferation Division of the National and Homeland Security (N&HS) Directorate. This relationship between groups allows for a positive and productive collaboration among scientists, engineers, software developers, and project managers.

1.2 The DRCT Development Group

The DRCT group consists of the following personnel:

Tim Roney	Principal investigator and group lead
Bob Pink	Mechanical engineer
Robert Seifert	Electrical engineer and systems support
Karen Wendt	Radiographer and systems support
Mike Smith	Electrical and software engineer (Idaho State University)

1.3 Report Overview

The remaining six sections of this report provide the following discussions:

- A brief history and perspective on DRCT single munitions scanners
- Review of market surveys and experiments performed to determine the optimum low-energy x-ray generation subsystem for the DRCT scanners
- Summary of the search for a new x-ray detector for the DRCT scanners and preliminary results from a new detector
- Ergonomics and user interactions
- Efforts to integrate PINS and DRCT including software development for volume estimation, conceptual designs for portable mounts/carts for large objects and mechanical or electronic designation of volumes of interest
- Report summary.

2. PERSPECTIVE ON THE SINGLE MUNITIONS DRCT SCANNERS

2.1 Original Development

The DRCT portable scanning system concept was initially proposed in 1997 as part of a research and development (R&D) project for PMNSCM. Following the success of the first scanner demonstration at Spring Valley in the Washington, DC area in April 1999, several additional single-munitions scanners were commissioned and several other larger scanners were developed for large drums and ton containers. The portable single-munitions scanners evolved from an early concept that separated gantry and electronic control to one that incorporated gantry and electronics on the same platform and finally back to separated gantry and electronics. Figure 1 shows two of the earlier model DRCT scanners. Figure 1A is the first system developed in 1998 and deployed in 1999. The detector interface and motion controls are mounted on the back of the gantry. The control computer is a field-portable unit separated from the gantry. Figure 1B is the original DRCT-5 developed for Pine Bluff Munitions Assessment System (PBMAS). The detector interface, motion control and computer are all mounted on the back side of the gantry.

(A)

(B)

Figure 1. Early versions of the DRCT scanner. (A) First system developed in 1998 and deployed in 1999; and (B) The original DRCT-5 developed for PBMAS.

2.2 Current Status

The current DRCT single munitions scanning system uses a 300kVp, 3mA Yxlon Smart 300 HP portable x-ray generator, a Thomson (or Thales) linear diode detector array, and both vertical and rotational scanning capabilities to enable single projection digital radiography and computed tomography (see Appendix B). The system was originally designed for standalone single munitions or munitions residing within various types of overpacks. The systems have been used to scan thousands of munitions and related objects over the past 12 years (since 1998). There are six systems in the inventory, referred to as DRCTs 4, 6, 7, 8, 9, and 10. The two detector systems (Thomson or Thales) are identical at the front end (where the x-rays are converted to visible light) but are different in terms of their read-out electronics. This has led to two slightly different electronic box configurations. Figure 2 shows the most recent DRCT scanner.

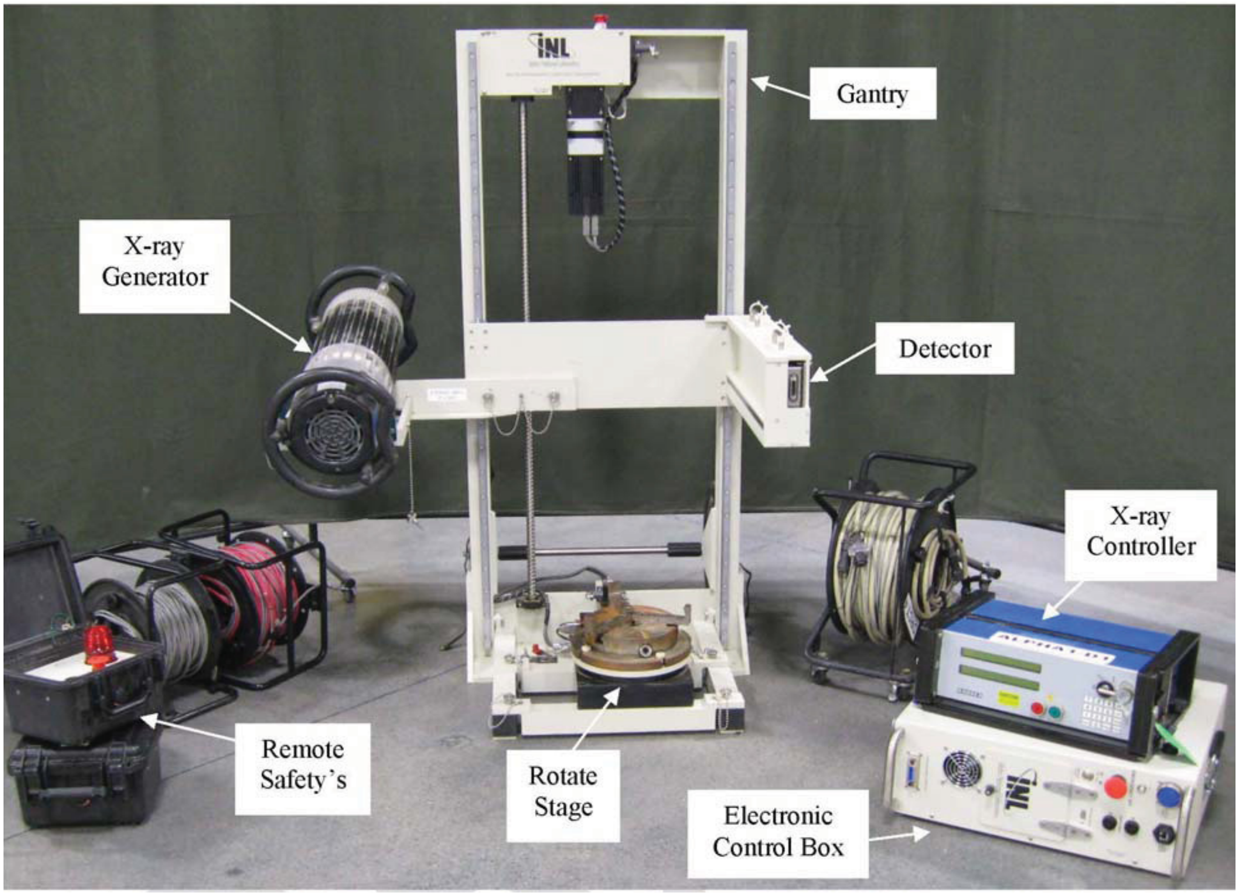

Figure 2. The most recent DRCT portable scanning system. All electronics are separated from the gantry and are contained in the electronics control box.

2.3 Capabilities and Limitations

The specification sheet provided in Appendix B infers the range of objects that can be inspected and some of the limits of the DRCT systems. In a report provided to PMNSCM this year, Shaw Environmental, Inc. pointed out several capabilities and limitations of the DRCT systems based on an independent evaluation and interviews with several users by The Shaw Group Inc.[a] Some of the deficiencies reported require research and development while others are simple "fixes" related to mechanical issues. Most importantly the Shaw report reflects the need to expand the capability of the portable systems to accommodate larger objects especially when contained within overpacks and the need for higher energy sources. In addition, Shaw mentions an interest in distinguishing solidified heels from liquids in a container, investigating detection limits for explosives, investigating stationary area detectors in lieu of (or as supplements to) scanning linear arrays and establishing a set of exposure parameters for commonly encountered munitions types. Our present focus is on the effort to accommodate larger objects though we will be considering these other interests as opportunities arise. This report covers our efforts to better understand and document the source and detector limitations and what we can do to improve upon these.

[a] The Shaw Group Inc., 2010, "Updated X-ray Technology Whitepaper," Deliverable D035-3.3.17, April 2010.

2.4 Paths to Improvement

To improve image quality overall and to increase the inventory of munitions that may be adequately scanned with DRCT systems, it has been recognized and recommended that the system components and capabilities be reviewed and enhanced or improved. Table 1 presents a summary of the possible enhancements that are under consideration or are actively under development.

For image quality improvement and to increase the range of containers that are adequately scanned by DRCT systems the most direct approach is to advance the capabilities of the two main imaging components: source and detector. The primary source improvement is to increase the energy and flux of the x-ray spectrum exiting the tube head and to optimally select source energy for specific objects. The tradeoff here is that it is not possible to increase source power substantially without incurring additional weight. Possible detector improvements include higher efficiency, higher spatial resolution matched to a source with correspondingly smaller spot size and dynamic range. These issues are addressed in the following sections.

Additionally, it is possible to improve image quality via modifications or entire revisions to the existing DRCT data acquisition, processing, display and storage software. Ultimately, the entire DRCT software package will need to be modernized due to changes in the operating system and to coordinate advances in detector software but we are not currently working on software improvements with respect to image quality.

For field of view (FOV) improvement, the approach would be to either increase the length of the detector array or to enable a mode of data acquisition that allows for multiple passes where either the object or the detector is displaced by a fixed amount between passes and the ensuing data is assembled in a mosaic to form a complete image.

The major focus in FY-10 was on investigating advanced detectors that may serve as a replacement for the existing set of DRCT system detectors. In addition to system improvements, it has been realized there are no replacements for those detectors currently operating on the DRCT scanners. Neither Thomson nor Thales manufactures the models presently used on the DRCT scanners and the secondary/used market for these detectors is extremely sparse. Hence, a replacement for these aging detectors is also required.

Table 1. Paths to improve DRCT systems.

Improvement / Mechanism	Image quality	Field of view	Information transfer	Ease of operation
Source enhancement	Higher kVp, mA			
Detector enhancement	Higher efficiency Higher dynamic range	Increased length		
Gantry enhancement	New data acquisition modes	Multiple pass Discrete placement of detector	Volume of interest marker (for PINS)	
Software enhancement	Signal averaging	Mosaic images	Software to support container marking RFID Tags.	
Operational modifications	New data acquisition modes	Additional steps to move detector	Additional step to mark container	User Evaluation(s)

3. X-RAY GENERATION

3.1 Existing X-ray Generation

DRCT systems presently deploy the Yxlon (formerly Andrex) Smart 300 HP portable x-ray generators. Yxlon, Inc. has gone through many management changes over the past several years and is currently owned by Comet Holding GmbH. The Smart 300 Series has performed well over the years of service however; we are currently experiencing quality problems with the service provided on repairs of the Smart 300s. The quality problem (in part) prompted an effort to review other options for portable generators that will be discussed later in this section. For the foreseeable future, it seems likely that the Smart 300 HPs will still play a prominent role in the DRCT scanners, though it is possible that other supplemental systems will be deployed. Some of the issues concerning present and future sources of x-ray generation are also discussed in this section.

Two driving factors prompted a market review of available x-ray generator systems: the limitation on penetrability and dose provided by a 300kVp, 3mA x-ray generator—it is insufficient to provide adequate dose for imaging 155 mm and larger shells; and the current problems with unreliability of repairs. The results of the x-ray generator market review revealed a dearth of commercially available portable systems but prompted an interest in systems from Industrial Control Machines (ICM), Inc.

The most notable and potentially useful generator is the ICM 360kVp, 5mA generator. Due to its higher potential and current with respect to the Yxlon Smart 300 HP, it was deemed useful to perform a comparison study of the two x-ray generators. However, an ICM 360kVp system could not be located in time to perform a test. A 320kVp, 6mA ICM system (D3206) was located and is included in this study. While not the most powerful system in its class, a test of the ICM D3206 allows us to test the validity of the published specifications with respect to dose output.

The complete details of the source study are provided in "X-ray Generator Evaluation,"[b] but the results are summarized here.

Two separate source comparison studies were performed: Yxlon Smart 300 vs. Yxlon Smart 300 HP; and Yxlon Smart 300 HP vs. ICM D3206. The first study had a goal of verifying Yxlon's claim of a substantially higher dose output from its HP series vs. its older (non-HP) series of source systems. The second study had a goal of determining if the ICM x-ray generators were sufficiently powerful to warrant investment in a new line of generators for the DRCT systems. In both studies, it is important to be aware the comparisons were between systems that have been deployed in field conditions for several years. A better way to perform the comparisons would be to use new equipment, but that was not an option.

3.1.1 Yxlon Smart 300 vs. Yxlon Smart 300 HP

Figure 3 shows the experimental setup and the results for the Smart vs. Smart HP study. This study was performed at INL's DRCT laboratory housed in the Idaho Accelerator Center's Airport Facility. A standard measurement to determine dose is obtained by first measuring the unattenuated dose at a fixed distance from the x-ray spot inside the tubehead and subsequently repeating the measurement with increasing thicknesses of an attenuating material (steel in this case). This test is intended to obtain results similar to those published in the Yxlon Smart user manuals. A Radcal Corporation 2025 meter and ion chamber probe was used for this test. Results are shown in Table 2. The graph in Figure 3D verifies the Smart HP model exceeds the dose of the original Smart model but not by as much as published in the Yxlon manual. The manual claims the Smart HP produces 1000 R/hr at 1 m from the source while the original Smart produced (per the manual) 600 R/hr at 1 m. This implies an improvement of about 67%. If we convert our measured results from R/min and use the inverse square law to project dose out to 1 m (from 700 mm) we get the experimental values of 608 R/hr for the Smart HP and 482 R/hr for the older

[b] Seifert, Robert, 2010, "X-ray Generator Evaluation," DRAFT, 2010.

Smart system. Note: Even though neither system achieved its published output in this study, the advantage in dose provided by the Smart HP system was 26%.

Table 2. Results of Yxlon Smart 300 HP vs. Smart 300.

X-Generator Comparison							
Thickness	Smart 300HP (R/min)	Smart 300 (R/min)	% increase	Smart 300HP (R/Hr) @ 0.7 m	Smart 300 (R/Hr) @ 0.7 m	Smart 300HP (R/Hr) @ 1 m	Smart 300 (R/Hr) @ 1 m
0.00	20.7	16.4	20.77295	1242	984	608.58	482.16
0.25	5.36	3.55	33.76866	321.6	213	157.584	104.37
0.50	2.47	1.53	38.05668	148.2	91.8	72.618	44.982
0.75	1.242	0.7	43.63929	74.52	42	36.5148	20.58
1.00	0.647	0.34	47.44977	38.82	20.4	19.0218	9.996
1.25	0.349	0.17	51.2894	20.94	10.2	10.2606	4.998
1.50	0.19	0.09	52.63158	11.4	5.4	5.586	2.646
1.75	0.106	0.05	52.83019	6.36	3	3.1164	1.47
2.00	0.058	0.025	56.89655	3.48	1.5	1.7052	0.735
2.25	0.032	0.013	59.375	1.92	0.78	0.9408	0.3822
2.50	0.019	0.005	73.68421	1.14	0.3	0.5586	0.147
2.75	0.01	0.002	80	0.6	0.12	0.294	0.0588
3.00	0.004	0	100	0.24	0	0.1176	0

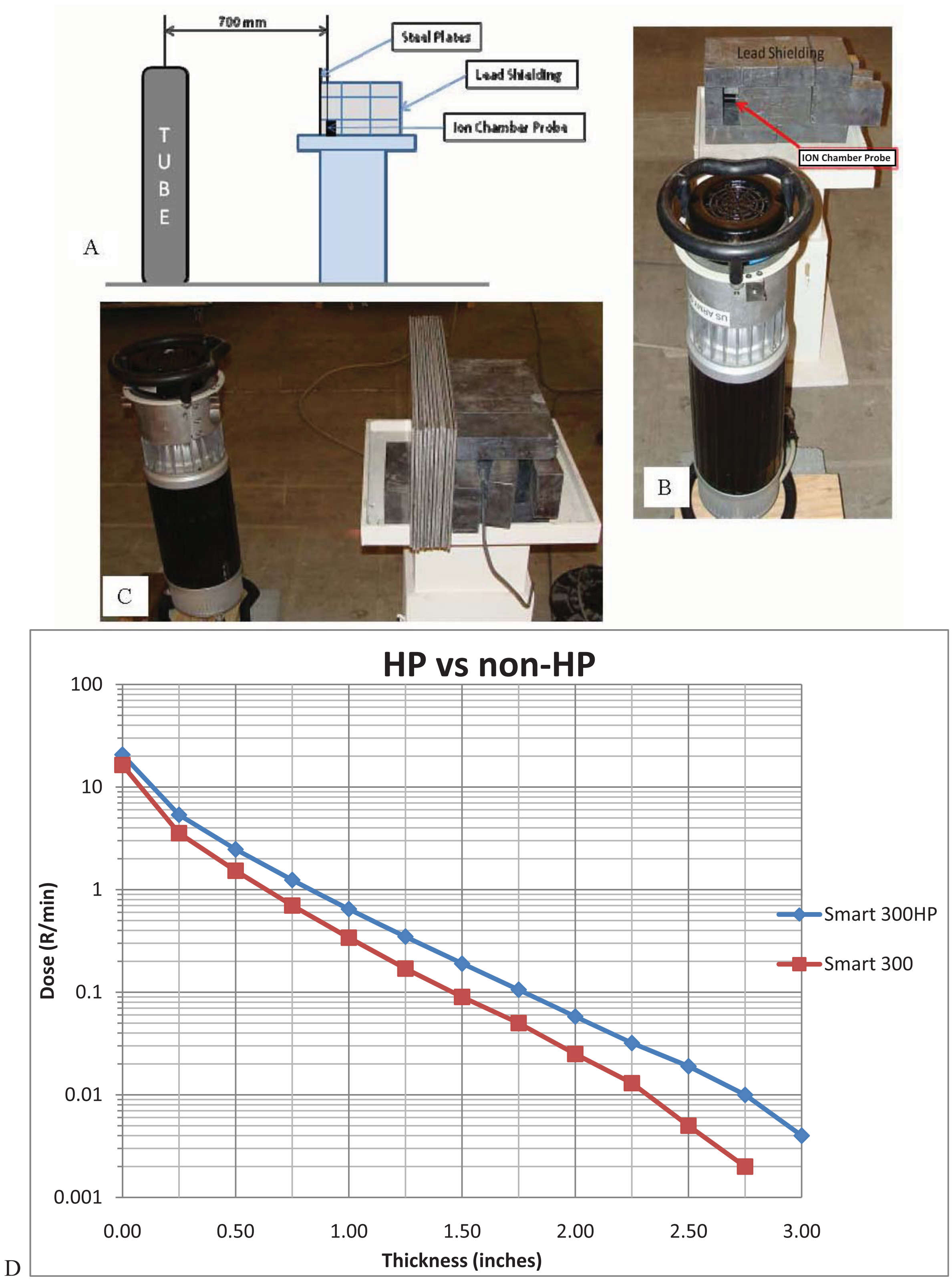

Figure 3. Yxlon Smart 300 vs. Yxlon Smart 300 HP output test: (A) Graphical depiction of the experimental setup; (B) Ion chamber probe behind lead shielding; (C) Side view showing steel attenuation plates; and (D) Dose output of both generators.

3.1.2 Yxlon Smart 300 HP vs. ICM 3206

The comparison study between the Yxlon Smart 300 HP and the ICM D3206 took place at Willick Engineering in Santa Fe Springs, CA. Willick provided access to the ICM x-ray generator and has ample facilities to support the test. A Radcal Corporation 2026C meter and a 20X6-60 probe were used for the measurements. Note that the meter saturates in this study when there is no attenuating material between the generator and the meter. Figure 4 and Figure 5 show the configuration and key results. The result shown in Figure 5 illustrates the Smart 300 HP actually produces a higher dose at 300kVp, 3mA than the ICM D3206 at 320 kVp, 6mA does.

After running the ICM and the Yxlon systems side by side, it was noticed the Yxlon Smart 300 HP had a few features the ICM did not. The ICM unit must be turned off in order to adjust the kV or mA while the Yxlon allows the operator to change the kV and mA on the fly. The ICM "ramps up" a lot slower than the Smart. The ICM would require new code to be written in order to remotely control the unit. The Yxlon systems have a metal ceramic internal tube while the ICM units have a glass internal tube. The metal ceramic tube is more durable when used in the field.

The conclusion from these two studies is the Smart 300 HP x-ray generator should remain the generator of choice for now when considering energies below 420kVp. We have found Willick Engineering to be a competent vendor for the tests we wanted to perform. We may also engage them for repair work in the future to avoid some of the difficulties we are currently experiencing with Yxlon, Inc.

Figure 4. The x-ray cave at Willick Engineering. The two x-ray tube heads under test are the far left (ICM D3206) and the far right (Yxlon Smart 300 HP). The center tube head belongs to Willick. Variations on the attenuating material and thickness were used to derive dose results for the two systems.

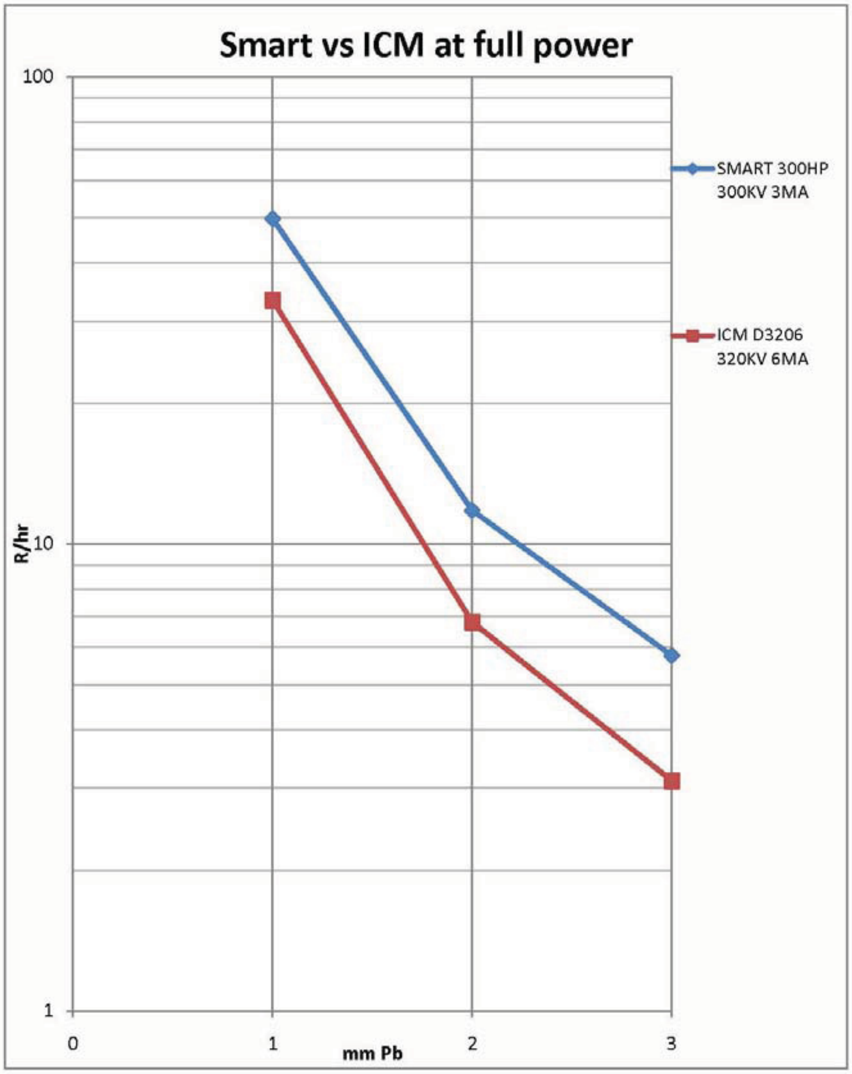

Figure 5. Results of the comparison between the Yxlon Smart 300 HP and the ICM D3206 x-ray generators.

3.2 Possible Improvements at the High End (Linacs, Betatrons)

Years of experience with the 300kVp x-ray generator and recent studies validate the need for a higher power x-ray generator when imaging any munitions that are 155 mm or larger, especially when contained within a metal overpack and the region of interest is near the bottom of the munitions. Presently the options for higher energy are limited to 450kVp x-ray generators, portable linear accelerators, betatrons, and isotopic sources. Experimenting with combinations of 450kVp x-ray generators and new detectors (see detector development section) is in process. It appears from these studies there is an improvement in x-ray penetration of a 155 mm munitions with 450kVp and more efficient detectors and hence an improvement in image quality. However even higher energies will be required for anything larger or when a 155 mm shell is placed in an overpack. Hence, the interest here is primarily in portable sources of megavolt energies. Investigation of higher energy sources is a planned task for FY-11. Major considerations include cost, transportability (both size and weight), dose for image quality, dose concerns for radiation safety, and detector efficiency.

4. X-RAY DETECTION AND IMAGING

There are two driving factors behind the investigation and development of an advanced detector for DRCT systems. First, the existing suite of detectors is no longer sold and no longer supported by manufacturers. Second, we are seeking to improve the image quality and hence the interpretability of DRCT images. We have performed a search of potentially viable portable linear detector arrays (table in Appendix C) and found what appeared to be a promising detector, a Detection Technologies (DT), Inc. linear diode detector array. DT offers a line of off-the-shelf detectors and also allows one to customize key detector features such as depth and width of scintillation elements (within limits). Due to the project's late start in the fiscal year we chose to acquire a more readily available, nearly off-the-shelf, detector that was closely matched to the existing DRCT detectors in terms of configuration. The table in Appendix D lists the key features of the DT detector. The detector arrived in late July and is still in the early stages of testing. Based on the results seen to date (summarized in the following paragraphs) we believe the DT detector (or a variation from DT of the one acquired) is a promising alternative to the existing detectors used on the DRCT scanners.

4.1 Detection Technologies, Inc. Detector

The DT detector acquired this year is a 1280 element linear diode detector array. Each element is 0.3 mm in width, with a 0.4 mm pitch, yielding an overall detector length of 512 mm (Figure 6). This is longer than the current DRCT detectors which are 1024 elements by 0.45 mm or 460.8 mm in length. The table in Appendix D provides a comparison of the DT detector and the two LDAs used on the DRCT systems. The most attractive aspect of the DT detector is the scintillation material, cadmium tungstate ($CdWO_4$). $CdWO_4$ is a slightly higher density (ρ=7.9 g/cc) material than gadolinium oxysulfide (Gd_2O_2S, ρ=7.4 g/cc). Gd_2O_2S is used in the current set of DRCT detectors. While several aspects of x-ray conversion to visible light are comparable between $CdWO_4$ and Gd_2O_2S, $CdWO_4$ is nearly transparent to the scintillation light it produces and hence can be made much thicker than Gd_2O_2S which is nearly opaque to its scintillation light. This enables $CdWO_4$ to be far more efficient than Gd_2O_2S as the additional thickness leads to substantially more stopping power. The depth of the scintillation elements in the DT detector acquired is 3.15 mm.

Figure 6. Detection Technologies Detector. The active line of the detector is along the top (note the arrow).

4.1.1 Initial Testing of the Detection Technologies Detector

The DT detector was received in July, 2010. It has subsequently been run through a series of preliminary tests to verify functionality and to begin evaluation of the quality of the product. Two testing configurations were arranged: temporary mount onto a scanning DRCT gantry system and temporary stationary mount on INL's large x-ray imaging system.

4.2 DT Detector on a DRCT Gantry

Setup: Although the detector is rated up to 450kVp, when delivered it does not have sufficient shielding of the electronics to be operated under high doses. Tungsten has been ordered that will be used to construct both shielding for the electronics and collimation for the active area of the detector. Until the shielding is in place, the detector could only be operated in a scanned mode on the DRCT scanner up to about 160kVp. Also, the configuration of the detector is different from the existing detectors on the DRCT scanners. The detector is larger and has its cable connects on the opposite side. Hence, a new mount is required. For the first set of tests, a temporary mount was constructed (Figure 7). Finally, the software provided by the manufacturer to communicate with the detector is archaic. Until new software is written (planned for FY-2011), the data acquisition will run in a semi-automatic mode, where the x-rays and scanning are initiated by the usual DRCT interface and the detector is controlled synchronously but under operator control using a separate computer.

Operation: The DT detector requires calibration in a similar fashion to the older detectors. An internal detector offset and gain calibration sequence is required anytime the detector is turned on (while warming up) when there are significant temperature changes and when the object under inspection requires a substantial change in the source operating parameters (i.e., kVp and mA). The DT detector appears to have additional options associated with the choice of collecting data either with or without the calibration settings. Testing and understanding of these options has just begun. For the most common approach (collect and apply both offset and gain for all images acquired) several images have been collected. Shown in Figure 8 are the “dark” and “light” calibration traces that accompany a standard image acquisition for the DRCT scanners. The dark trace is simply a representation of the average value of each detector element when there is no x-ray irradiation. Hence the “data” in this case arises only from the inherent noise in the detector read out and digitization process. The light trace is a representation of the average value of each detector element when irradiation of the detector creates a near-saturation effect. These two traces are used to correct the raw image data in nearly all DRCT image acquisitions. The standard deviation of the read noise in the dark trace is depicted along the top of the image. In this case, the value is 13.842. This is the overall average of the standard deviation for each pixel and provides insight into the real dynamic range of the detector. The DT detector has a 16-bit analog-to-digital conversion system. Given the standard deviation of the dark (which is related to the read noise) requires just under 4 bits of information (four bits covers a range of values from 0 to 15), the indication is that the DT detector will provide greater than 12 bits of true dynamic range. In the literature, this would be stated as a dynamic range of > 4095:1. We can compare this to the true dynamic range of the current suite of DRCT detectors which is about 10 bits (> 1023:1). Thus we can expect significant image quality improvement from the DT detector with respect to the data range value. This should be more apparent when imaging very dense or thick metal objects.

A simple, low density object consisting of a step wedge, resolution phantom, fuse, and a battery charger was imaged at 100 kVp using the DT detector (Figure 7). Based on this image and the calibration data, we can conclude the detector is operational and providing reasonable images at the low exposure range.

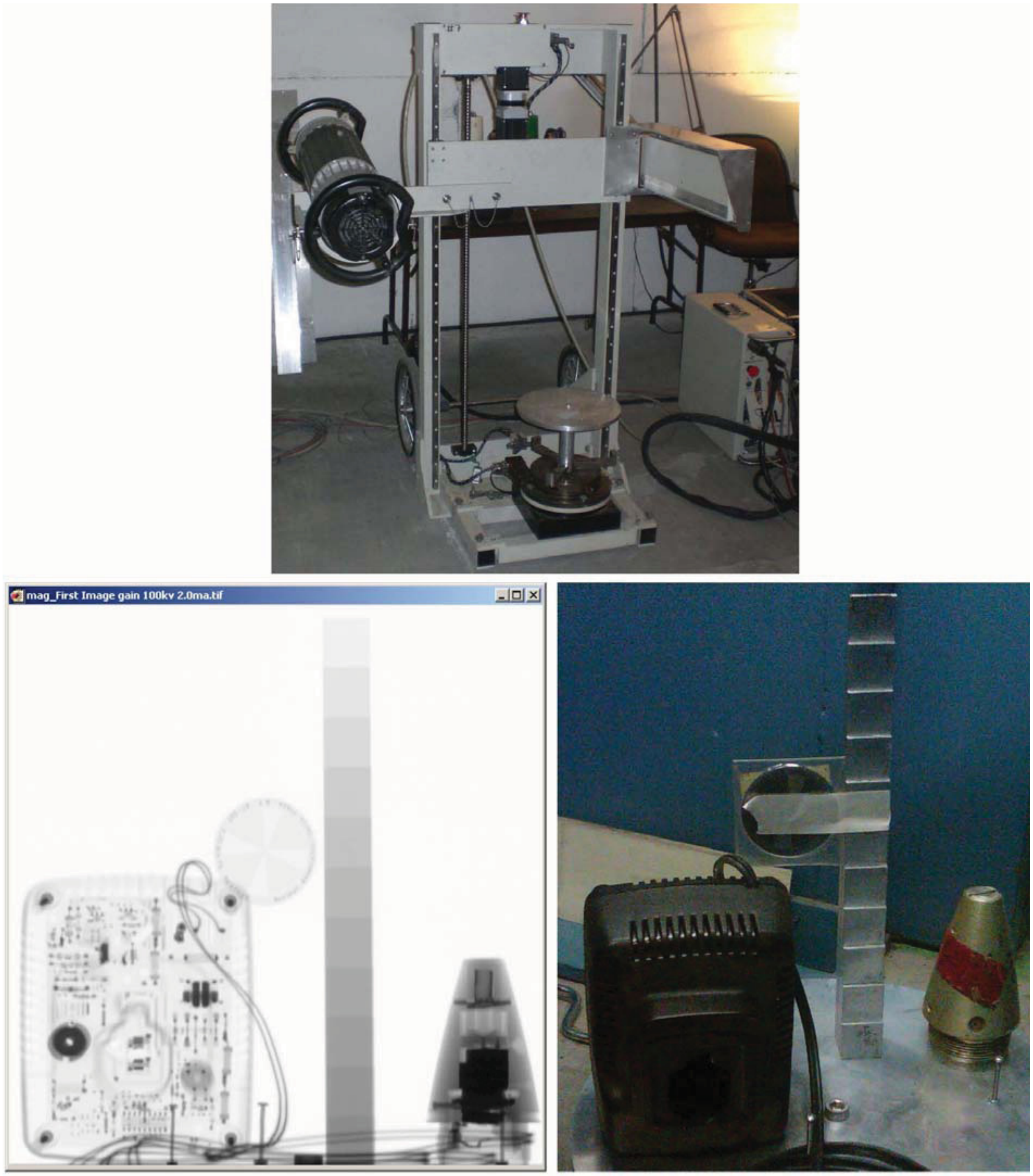

Figure 7. Clockwise from top. DT detector mounted on a DRCT scanner (DRCT-10). Objects to be imaged mounted on the rotate stage. Vertical-scan radiograph of the object obtained by using the DT detector mounted onto a DRCT scanner.

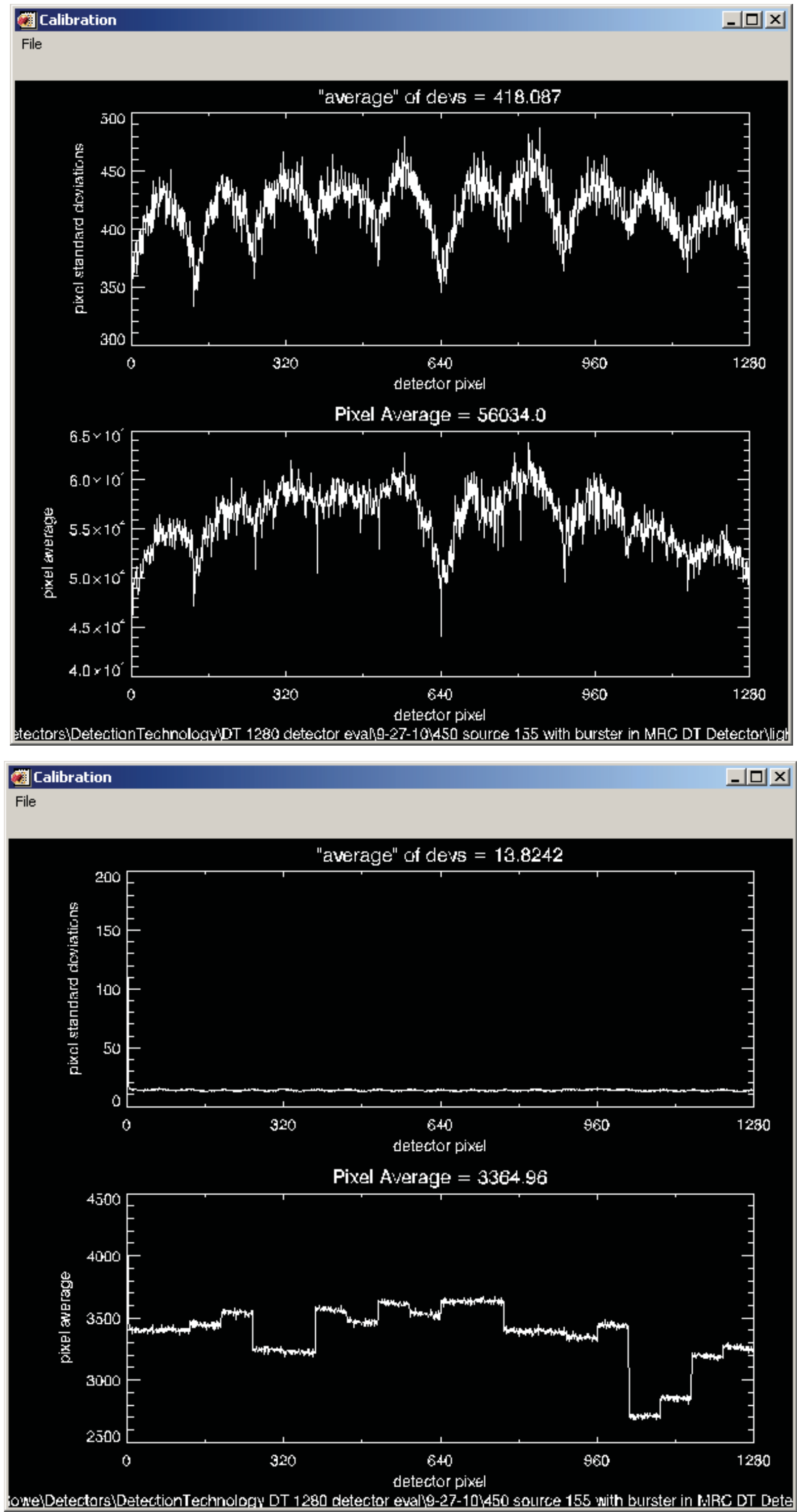

Figure 8. Dark (acquired 9/27/10) 800 lines with offset and gain set. Light (acquired 9/27/10) 800 lines with offset and gain set – 450kVp, 0.45 mA.

4.3 DT Detector on the INL X-ray Scanning System

In order to initiate tests with the detector using higher energies, the detector was placed in the INL large x-ray scanning system and shielded with a substantial quantity of lead bricks. The lead shielding inhibits any motion of the detector. However, the INL system allows for horizontal scanning of objects with a stationary detector. So acquisition of scanned images with a stationary detector is possible. In this configuration it is easy to set up for use of either the Yxlon Smart 300 HP x-ray generator or the Yxlon 450 kVp x-ray generator mounted to the INL system. Figure 9 shows the configuration for testing with a 155 mm shell contained horizontally in an overpack. The Smart 300 tubehead is placed on a stand in front of the object at about the same distance as the source-to-detector on a DRCT system. The DT detector is placed behind a stack of lead bricks with a small vertical opening for collimation. The object is horizontally translated.

Figure 9. DT detector set up on the large INL x-ray system.

In the interest of exploring the limit of the DT detector with respect to imaging 155 mm munitions (both bare and within overpacks) using both an Yxlon Smart 300 generator and an Yxlon 450kVp generator, images were acquired in a variety of exposure modes. Much of this effort was also intended to explore and understand the operational principles of the DT detector software and interface as well as its inherent capabilities. Figure 9 and Figure 10A depict the imaging configuration for the Yxlon Smart 300 tests. Note that when the higher energy tests are performed with the 450kVp generator, the Smart 300 is simply moved out of the way and the 450kVp tubehead (above the Smart 300 in Figure 10A) is lowered into place (see Figure 10B).

Three images are shown in Figure 10C, bare 155 mm shell exposed at 300kVp, 3mA, bare 155 mm shell exposed at 450kVp, 10mA, and the 155 mm shell contained within an overpack and exposed at 450kVp, 10mA. The images are shown lying down to reflect the horizontally scanning object protocol. Note the 155 mm shell contains a liquid level roughly half way up the shell when it is lying down. The liquid level can actually be seen all the way down through the thickest part of the 155 mm shell for the bare shell exposed at 450kVp, 10mA.

Based on early testing it appears the DT detector is a viable alternative to the existing detector on the DRCT scanners. In FY-11 testing will continue and efforts will begin to integrate a DT detector into the

DRCT scanning systems. There are several mechanical, electronic, software, and operational considerations. These considerations need to be coupled with the detector specifications we have to choose from. The dimensions of the scintillator material, the pitch between elements, and the overall length of the detector are options.

Mechanically, the detector needs to have permanent shielding and collimation incorporated and a new mount for the detector needs to be designed. One potential advantage is that the DT detector cables extend from the left (as viewed from the source side) whereas the current detector cables extend from the right. Cables on the left may be easier to support and handle.

Electronically, a choice must be made between a USB/LAN interface and a frame grabber. The DT detector acquired in FY-10 has the USB/LAN interface. The frame grabber interface remains to be evaluated.

A software interface needs to be written to control the detector. This interface will rely on software modules provided by the vendor. The total effort cannot be determined until the software engineer is able to evaluate and understand the vendor-supplied modules. The estimate is about three months of labor for this effort. The interface will provide control of the detector for data acquisition (timing, readout rates, etc.), transfer the image data from the detector to the host computer memory, and display the resultant images to confirm the image has been acquired.

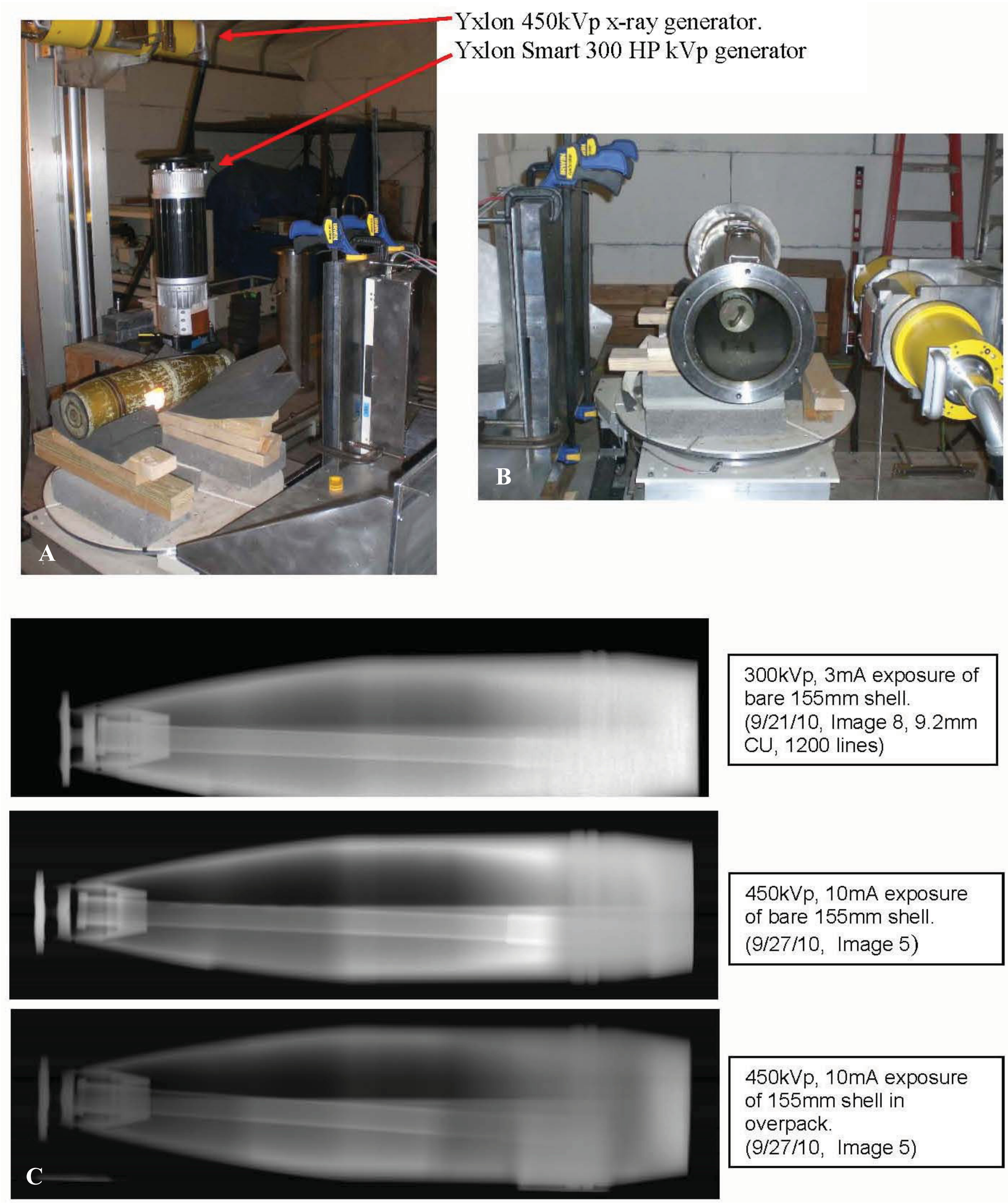

Figure 10. Qualitative comparison images of a 155 mm muntions with different x-ray generators. The variation in apparent size of the munitions x-ray images is due to slight configuration and magnification variations in the three image acquisitions.

5. ERGONOMICS AND USER INTERACTIONS

It was proposed in FY-10 to observe and interact with field operators during a field mission so any issues or ideas associated with improving the operational aspects of the DRCT systems could be directly recorded. Unfortunately, this task was not scheduled in FY-10 due to the late start of the project and the schedule for field missions. In fact, in the two cases that participation was hopeful (as observers) in field situations, the field operators completed their mission well ahead of schedule. Participation will be planned in a mission in FY-11.

Fortunately, Mr. Mike Rowan was in a DRCT training class prior to the Pueblo Chemical Depot (PCD) mission earlier this year. Partially due to our expressed interest in receiving more documentation from the field but largely due to Mr. Rowan's (and his colleagues, Richard Zucchero, Walter Oldenburg, Yancey Rhoden) initiative, a thorough recording of problems and issues associated with deployment of the DRCT systems was provided after the PCD mission. The spreadsheet shown in Table 3 represents a portion of the document Mr. Rowan provided. This spreadsheet will serve as a basis for our observation efforts in FY-11.

As mentioned in Section 2, the Shaw Environmental, Inc. report[a] on x-ray technology provides an excellent starting point to consider capabilities and limitations of the DRCT system. We will rely on the information in the Shaw report and new information gathered from the field to continue to refine DRCT field operations.

Table 3. A subset of the complete spreadsheet documenting problems (and resolutions) with the DRCT systems.[c]

DRCT #	Date	Time	Problem	Corrective Action	Minutes of Lost Operational Time	
8 w/DRCT 7 Andrex	06/08/2010	1018	System Bandwidth Error	Stop, Restart	6	33 Lost Operational Minutes on 06/08/2010
		1024	Error-10803 Digital Buffer Read	Shut down, restart, recal	27	
8 w/DRCT 7 Andrex	06/09/2010	0910	Error-10803 Digital Buffer Read	Shut down, restart, recal	24	130 Lost Operational Minutes on 06/09/2010
		0928	Error-10803 Digital Buffer Read	Left a message for Mike and talked to Stacey, awaiting a return call from Mike, Shut down, restart, recal	76	
		0948	Motors not working	Home Motors		
		0958	Recal Error MMAS (Alpha 404)			
		1000	Microsoft windows has experienced a problem and needs to close	Defrag, shut down, restart, recal		
		1117	Error-10803 Digital Buffer Read	recal, LAN connected	30	
		1250	follow-up with INL	Talked with Mike about errors and intermittent reconnecting with network message. He thought it was possible that we resolved the problem by connecting LAN.		
8 w/DRCT 7 Andrex	06/10/2010	1002	Motors error	Home Motors	4	4 Lost Operational Minutes on 06/10/2010
8 w/DRCT 7 Andrex	06/11/2010	0914	Error-10845 Digital Buffer	disabled WAN	20	54 Lost Operational Minutes on
		0941	mA error	Andrex shut down, rest, restart	8	
		1225	Error-10845 Digital Buffer	Alpha shut down, restart, disable windows automatic updates	26	
8 w/DRCT 7 Andrex	06/14/2010	1039	Hot Lamp Panel	Andrex shut down, rest, restart	2	2 Lost Operational Minutes on 06/14/2010
8 w/DRCT 7 Andrex	06/15/2010	1347	Error-10845 Digital Buffer	Shut down, restart, recal	17	49 Lost Operational Minutes on
		1410	Error-10845 Digital Buffer	Shut down, restart, recal	19	
		1523	Error-10845 Digital Buffer	Shut down, restart, recal	13	
8 w/DRCT 7 Andrex	06/17/2010	1006	Bad Image, snow at top of image	new dark, new offset, re-image munition	5	12 Lost Operational Minutes on
		1235	Motors communication error	shut down, restart Alpha	7	
8 w/DRCT 7 Andrex	06/22/2010	1033	Error- Labview followed by READ_TIFF	During a normal DRCT scan the Labview appeared. Shut down and restart Alpha. After restarting Alpha, attempted to process the image collected when the labview error appeared, the image initially appeared normal then closed. After a few more seconds the X-ray software morphed into something that is or is akin to the TC system. In the end the image appears fine after using a different DARK.	30	34 Lost Operational Minutes on 06/22/2010
		1316	mA error	Turn off control panel, restart control panel, restart munition scan/processing.	4	

[c] Rowan, Mike, Spreadsheet documenting problems from Pueblo Chemical Depot, 2010.

6. DRCT/PINS INTEGRATION EFFORTS

Three subtasks were initiated in FY-10 to support integration of the DRCT systems with the PINS systems:

1. Conceptual design of a cart to transport munitions from storage to the DRCT system and on to the PINS system
2. Investigation of methods to tag regions of interest in a container, identified by a DRCT scan, so that, when applicable, the PINS system can optimize placement of its source and detector to improve signal
3. Initiation of methods development for volume estimation of liquids and solids within a container.

6.1 DRCT/PINS Cart Conceptual Design

Several discussions were held among the PINS development personnel and DRCT personnel to determine what type of cart would be of value to field operators. The result thus far is the concept of a cart moving munitions from storage to the DRCT station then to the PINS station while maintaining position information (Figure 11). The object being examined remains in place on the cart, and the height and angular position of a region of interest found in the radiography operation would be stored for retrieval for further examination using the PINS operation.

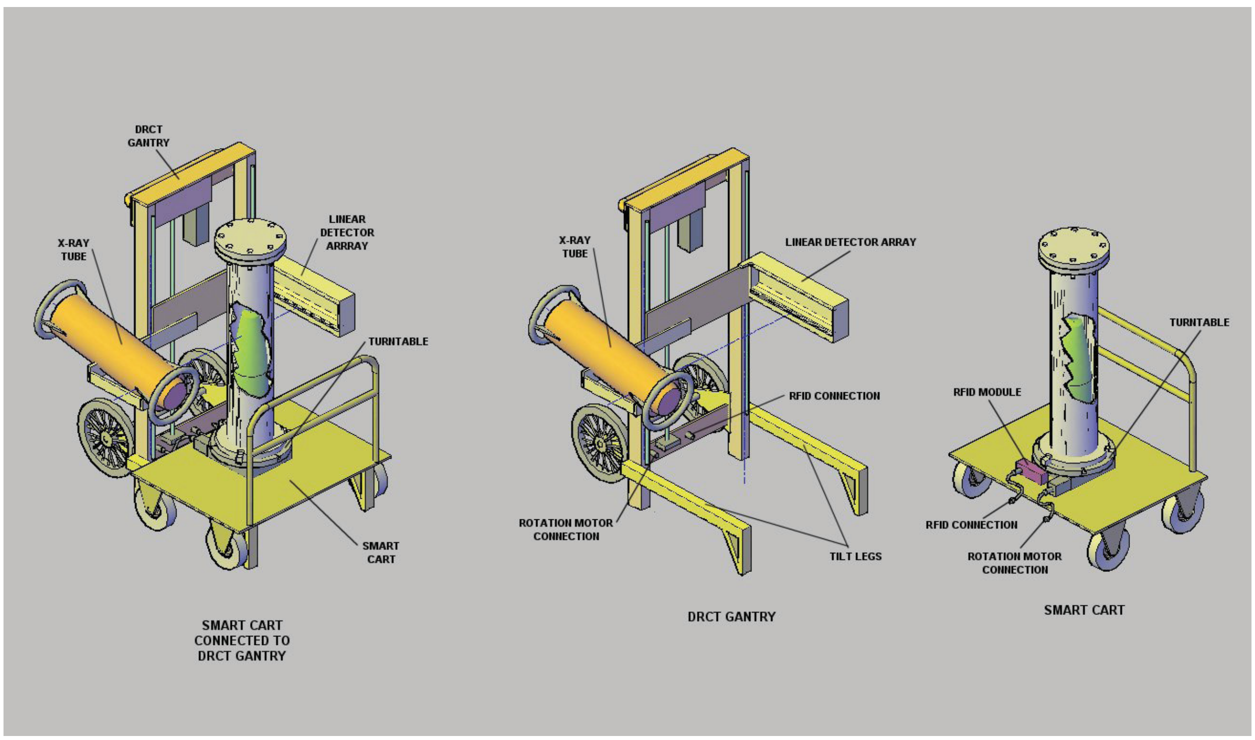

Figure 11. Conceptual design of a transport cart for DRCT and PINS patterned after the existing DRCT scanner gantry. The cart would retain a stage and mount for an object and its base would replace the rotate stage on the DRCT scanner.

The position information could be stored directly on the object, in a memory module that would be physically located on the cart, or in an RFID tag that could be affixed directly to the object. If the object were removed from the cart before the PINS operation is performed, a datum position could be marked on the object so it could be returned to the cart in the same angular orientation at a later time. A cable would be connected to the respective measurement system either at the instrumentation stand or its respective controlling computer so that motors could be controlled to orient the object properly for examination.

Motion capabilities being discussed include both rotational and vertical. Rotational capability would be both incremental and continuous. Incremental rotations would be for reorienting the object for acquiring radiographs at various angles or for positioning the object for optimal PINS data collection. Continuous rotation would be necessary for CT operations. Vertical motion capability, necessary for radiography, may be retained with the DRCT system, or be added to the cart if deemed necessary.

6.2 Tagging a Container with Region of Interest Information

We have considered both mechanical marking of a munitions container or electronic tagging via RFID tags. Both options are introduced here.

6.2.1 Mechanical Marking Systems

Options discussed for specifying where PINS measurements need to be performed on an object include physically marking the object where the region of interest is closest to the object's surface. This would be accomplished on the DRCT system. Three types of systems were investigated: an airless spray, a compressed air ink jet, and an air powered contact ink marker. Of these systems, the contact marker produces the best results.

Desirable attributes for the marking system are:

- The marking system should be easily installed on the DRCT gantry.
- The marking system components will not interfere with current DRCT operations.
- Marks put on the object should be large enough to be easily seen, but small enough to locate where PINS measurements should be performed with reasonable accuracy. A spot size of 1/4 was deemed desirable.

6.2.2 Airless Ink Spray

The airless ink spray produced the least desirable results. It was prone to continuous dripping, and for objects that were physically located more than 1 3/4 inches away, the spot diameter became larger than 1/2 inch. The DRCT systems were designed to accommodate object diameters up to 12 inches in diameter. To be useful the spray nozzle would have to be located just outside of the 12-inch object space. On smaller than 6 inches in diameter the spot size would be 1 inch or larger.

6.2.3 Compressed Air Ink Jet

The compressed air ink jet, shown in Figure 12, is an off-the-shelf product manufactured by Carco Incorporated. It produced near acceptable results. The primary problems consisted of the ink droplets that exploded from the nozzle, which would drop before impacting the designated object. The ink had a tendency to run, producing a vertical streak below the impact point. Also, as the distance from the jet nozzle increased the ink jet broke into multiple droplets. The dropping could be accounted for in the DRCT operations software, but to do so the DRCT operator would have to measure the distance from the jet nozzle to the object for every object radiographed, thus increasing the work steps necessary. Alternative inks were not investigated because the ink used for the testing is already considered to be a fast drying ink.

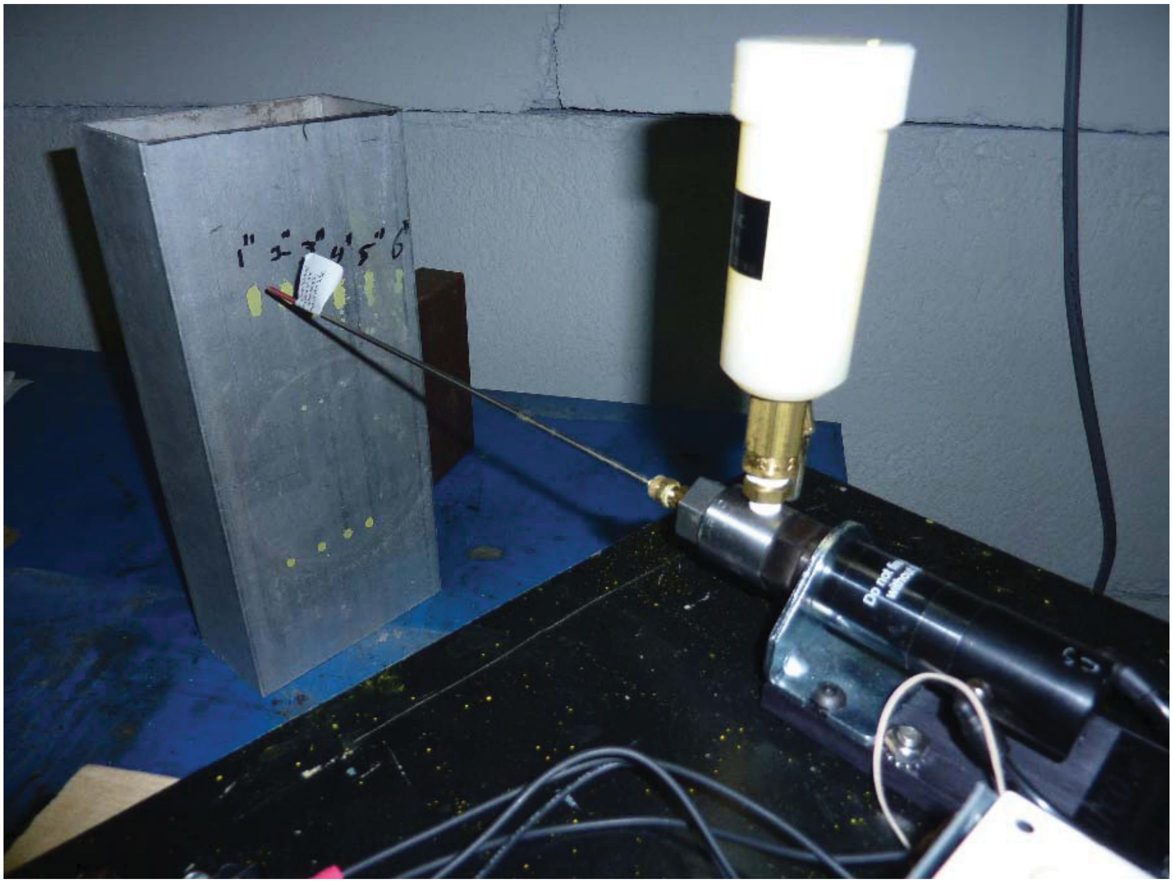

Figure 12. Compressed air inkjet test setup.

6.2.4 Contact Ink Marker

The contact ink marker, shown in Figure 13, is also manufactured by Carco Incorporated. It is an additional component added to the ink pump of the ink jet system. The component consists of a felt tipped marker mounted on the end of a dual action air actuator. A plastic cover mechanism which helps to keep the felt tip from drying out is also included. The contact marker produces consistent round dots without dripping or ink running problems. The felt tips are available in various sizes from 1/8 to 1 1/2-inches in diameter. A 1/4-inch-tip was used for testing.

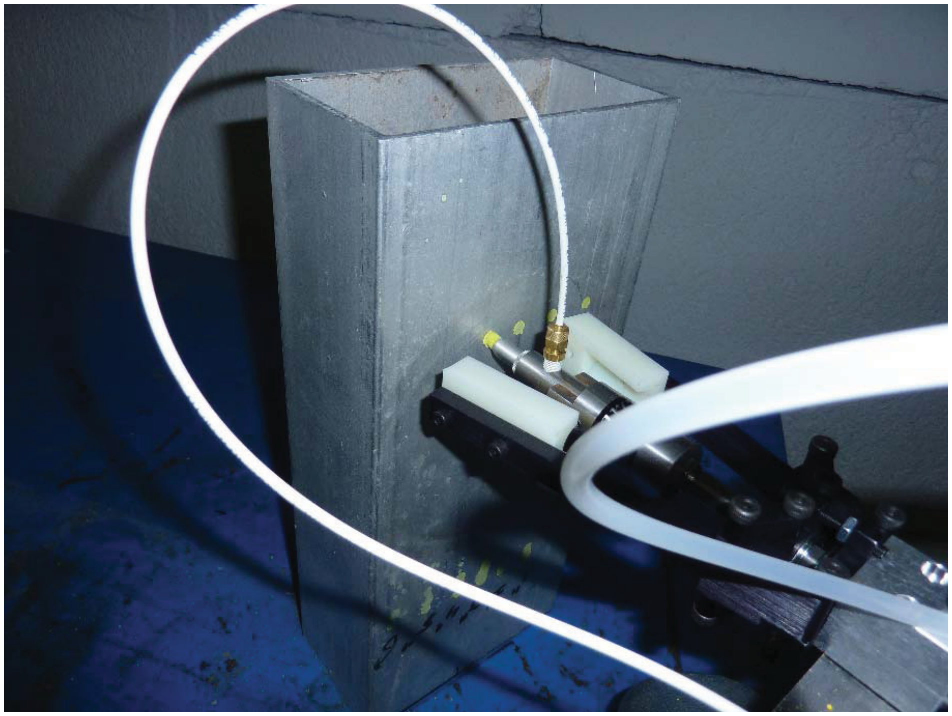

Figure 13. Contact ink marker test setup.

Additional components necessary for the marking system will include a small air compressor and air tank. These are available as aftermarket components for the use of inflating air shock systems on pickup trucks.

6.2.5 RFID Tags

We are reviewing two tagging systems from two vendors, the Texas Instruments Low Frequency (134 kHz) Micro RFID Evaluation Kit (Figure 14) and Thing Magic M5e-Compact RFID Evaluation Kit (Figure 15). They are briefly described here.

The Texas Instrument kit allows the user to input data onto a RFID tag of choice. When using this kit, an R/W (Read/Write) or MPT (multipage transponder) tag may be used. The R/W tag is limited to 80 bits of data while the MPT allows for 1360 bits. If using an R/W tag the user could simply label the tag with the munitions name and coordinates of the volume of interest inside the munitions. If using an MPT Tag the user could label the Tag with the munitions name, volume of interest coordinates and additional useful information. Data is entered using an ASCII format.

Texas Instruments Kit Contents:

- S2000 Micro Reader RI-STU-MRD1 Mounted on an Interface Board With
  - RS232 IF Port
  - Power Connector
  - Antenna Connector
- Antenna
- 9-Pin Sub-D Cable (Female – Female Connector)
- Various Transponder Samples
- CD With User Documentation and Demonstration Software

- Getting Started Guide
- 9V Power Supply Input 100V–240V, 1.5A.

Figure 14. Texas Instruments RFID tagging kit.

The Thing Magic kit works similar to the Texas Instrument (TI) kit. The main difference is the tags are higher frequency and can be read farther away from the receiver. The input method is the same as the TI kit. An R/W tag may be used and the data will be sent to the tag in an ASCII format.

Kit Contents:

- The embedded module running the MercuryOS operating system
- One 6 foot, 9-pin, D-Sub serial cable
- One antenna
- One coax cable
- One 9V power supply
- Antenna terminators
- International power adapter kit
- Sample tags
- CD-ROM containing the following:
  - Module Specific Developer's Guide

- Release Notes
- *Reader Assistant* utility for demonstrations, development, configuration, and debugging
- ArbSer utility and source code
- Supporting materials.

Figure 15. Thing Magic RFID tagging kit.

6.3 Volume Estimations

Interest has been expressed in determining the volume of both liquids and solids and the material center of mass within munitions using x-ray image data. In FY-10 the effort was initiated by deriving the internal capacity (volume) of a 155 mm shell as a function of height within the shell. A drawing[d] was used as the basis for the first estimate. Dimensional information derived from the paper drawing was used to build an electronic (CAD) drawing with Autocad (Figure 16A). Volumes of small vertical slices were then calculated using an Autocad function. The discrete volumes were used to derive the graph in Figure 16B. This data may serve as the basis for an estimation routine that uses height information derived from an x-ray image and a look-up table to return liquid volume as a function of height. In FY-11, plans are to repeat the liquid volume estimation process described above for several of the more common munitions. A series of calibration tests involving image acquisition of partially liquid filled munitions where the liquid volume is known prior to pouring into the munitions will also be performed. The long term goal is to develop and incorporate a liquid volume estimation routine into the DRCT image display and analysis program.

INL is also interested in developing the capability to derive the volume of a solidified heel from either a very few number of x-ray projection images or from a full computed tomography data set. This is a more long term effort that requires two distinct efforts:

[d] Ordinance Corps, 1941, Drawing used as basis for the first volume estimation, October 28, 1941.

- The capability to differentiate solids from liquids when they are both comprised of the same chemical formula and may have only slight differences in density
- Estimation of the volume once the solid and liquid volumes have been isolated.

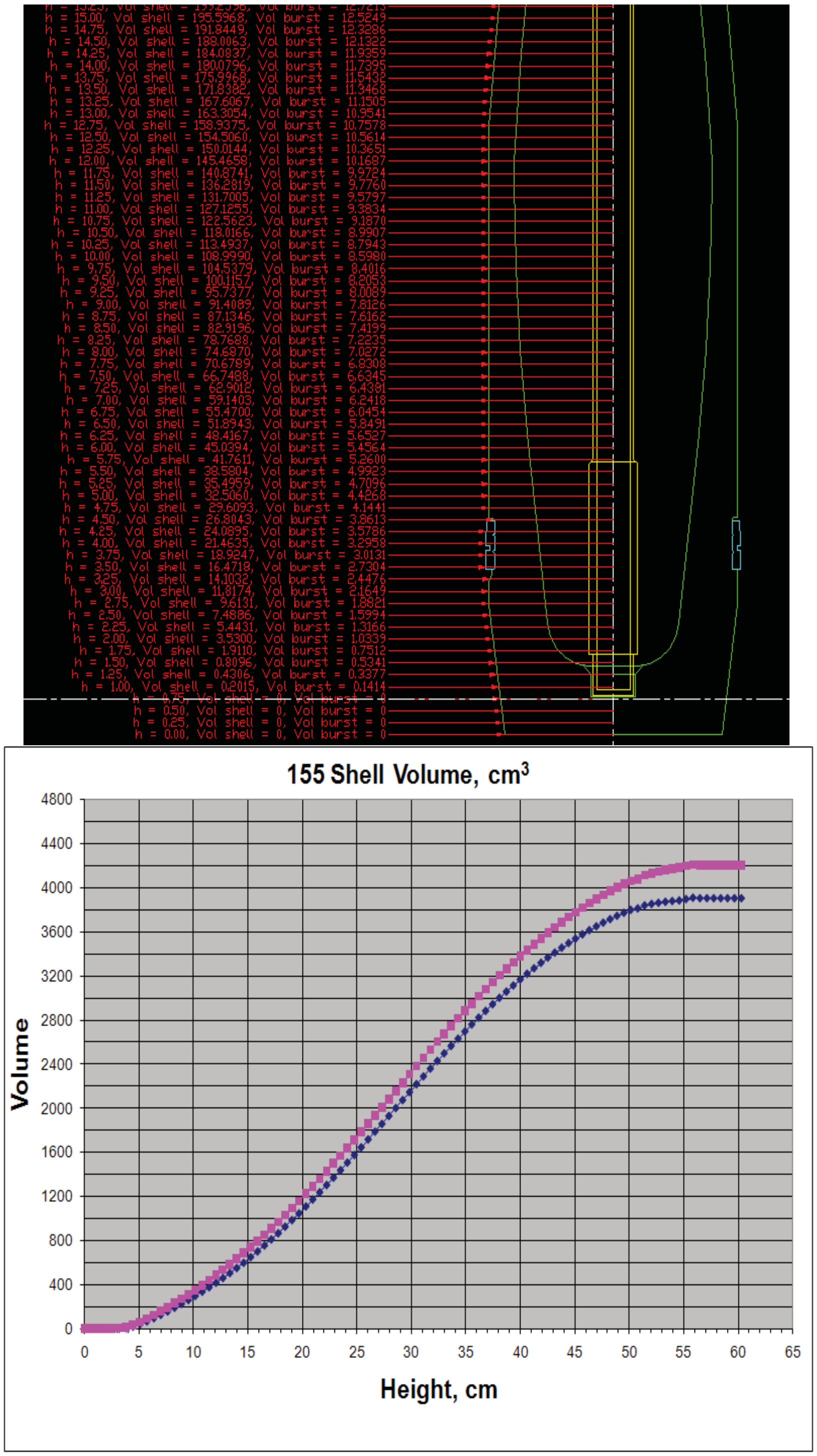

Figure 16. (A) Snapshot of the process for estimating volumes of thin slices of an object and the graphical result of summing the individual volumetric slices to obtain an overall volume as a function of height in a 155-mm munitions. (B) The blue (lower) line represents the volume when the burster is in place. The magenta (upper) line represents the volume when there is no burster.

7. SUMMARY

The emphasis in FY-10 was on the improvement of the source and detector for the single munitions DRCT scanners. For each component there are compelling reasons to develop solutions as soon as possible. Most importantly, due to the lack of available direct replacements for the existing detectors, a new detector specification must be provided as soon as possible. The Detection Technology detector will continue to serve as the basis of INL's detector development. Plans are in place to continue investigating this detector and developing the necessary support (mechanical, electronic, and software) in FY-11 to the point of it serving as the model for the new detector for the single munitions scanners.

Results of the tests performed on x-ray generators led to the conclusion that the Yxlon Smart 300 HP is still the appropriate choice for the single munitions systems. In FY-11 interest will shift to higher energy x-ray sources that will likely mount on larger x-ray inspection systems and will offer more penetrability for thick (> 155 mm) objects.

Several DRCT/PINS integration subtasks were initiated. Conceptual design was initiated for a transport cart that would enable movement of an object from a storage point to the DRCT scanner and to a PINS station. The cart would initially provide rotational motion for the object and could directly couple into the current DRCT gantry. Key information from the x-ray scan could be placed on the object via either a mechanical tag (i.e., ink marking on the object) or an electronic tag (such as an RFID tag). Several options are being considered for this information transfer. Additionally, efforts were initiated to perform volume estimation calculations for liquids inside standard sizes of chemical munitions. With the exception of the mechanical tagging, the DRCT/PINS integration subtasks are proposed to be continued in FY-11.

A recent driver for the PIP work is the recognized need for improved imaging capability for large objects. The DRCT systems are presently optimized for providing complete images of objects smaller in steel thickness than 155 mm munitions. In order to enable the DRCT systems to provide images of larger diameter objects, improvements are needed in x-ray generation, x-ray detection, and image processing. An underlying theme in all efforts for 2011 will be to expand the capability of DRCT systems to improve image results for larger objects.

Appendix A

DRCT Product Improvement Plan FY-10 Statement of Work

Appendix A

DRCT Product Improvement Plan
FY-10 Statement of Work

FY10 Statement of Work

Non-Stockpile Chemical Materiel
DRCT Product Improvement Plan

Task Description – The U.S. Army Project Manager for Non-Stockpile Chemical Materiel (NSCM) has developed a DRCT Product Improvement Plan (PIP) to improve the performance and capabilities of its existing systems.

Background – INL is the technology developer of the DRCT system now used by CARA (formerly the Army's 22nd Chemical Battalion and TEU) under the guidance of NSCM. They are most familiar with the technology and the Army application of the DRCT equipment. In continuing the implementation of the DRCT PIP, INL will remain the technology developer and Shaw will continue in its role as the NSCM Independent Technology Evaluator. Other contractors may be involved to provide specialized expertise or independent cost benefit analyses.

Scope of Work

1. DRCT End User Study

INL shall review literature and summarize hardware and software technology advancements that may have applicability and offer improvements to the NSCM program. INL shall then discuss these opportunities for program improvements with the end users, primarily NSCM project managers and CARA, and also catalogue problems with the existing systems, identify equipment limitations, and summarize desired capabilities the end users need to perform or better perform their mission. A potential list of topics to be addressed includes:

Initial study for improvements to the DRCT systems

<u>X-Ray Generation</u>

- Portable systems – Consider existing Yxlon Smart 300 models vs. alternative x-ray generators
- Appropriate generator for particular tasks (i.e., smaller tubes for smaller objects)
- Reliability, transportability and cost
- Review generators for possible use in new DRCT system designs.

<u>X-Ray Detection</u>

- Continued support of existing detector systems
- Requirements to maintain the current suite of non-replaceable detectors
- Recommend new detector systems for evaluation for current DRCT systems
- Review detector systems for possible use in new DRCT system designs.

Logistics and Ergonomics

- Determine optimum system dimensions for transportation to foreign locations
- Simplify setup and operation
- Lighter-weight chuck for securing object
- Alternatives to machine chuck for securing object.

Software Development

- Review current software for longevity
- Compatibility with evolving operating systems
- Compatibility with evolving software packages currently used by DRCT systems
- Evaluate potential modifications to current software
- Evaluate possibility of rewriting the entire image acquisition, processing, interpretation, storage, and reporting chain.
- Evaluate potential communications with PINS (heel location, PINS source and detector placement).

Portable Mount for Large Munitions and Unique Objects

- Ability to place object in front of detector when chuck is out of the way.

Miscellaneous

- Better, faster, cheaper
- CT reconstruction
- Improved alignment
- Reconstruction hardware
- Respond to end user personnel discussions.

Deliverable: INL shall issue a summary report with recommendations to NSCM for future work.

2. DRCT Detector Evaluation

The original manufacturer of the DRCT detectors no longer markets the style used on the current DRCT systems. Therefore, a replacement detector needs to be identified and evaluated.

In addition to evaluating compatibility with the current systems, INL shall also investigate the potential for image improvement. Specifically, INL review available detectors, acquire one for testing and develop the hardware and software to integrate with the existing DRCT systems (or use in new system designs).

Deliverable: INL shall provide a DRCT detector and supporting software compatible with the existing system that would offer equal or better performance than the current detector.

3. DRCT and PINS Integration

INL shall investigate and develop hardware and software to integrate the PINS measurement with the DRCT x-ray inspection protocol. Two likely hardware developments are: (i) an object mount that can be used interchangeably on the DRCT and PINS systems so that munitions could be transported directly from the DRCT system to the PINS system; and (ii) implementation of computer controlled vertical position of PINS hardware to automatically position munitions to the optimum location for the PINS measurement. Software modifications will be made to control positioning of staging on the DRCT system to automatically position PINS hardware or to provide guidance to PINS operators on placement of the PINS hardware to maximize signal. This task will be done in collaboration with PINS personnel.

Deliverable: INL shall provide the hardware and software described above to better integrate the DRCT and PINS systems.

4. Project Management

INL shall provide project management, cost reporting, review independent technology test plans or reports and participate in one NSCM project review in Edgewood, MD.

Appendix B

DRCT Single Munitions Scanner Specification

Appendix B

DRCT Single Munitions Scanner Specification

Gantry	
manufacturer	INL
model	DRCT-7
dimensions - completely assembled for data collection	
height	61
width	43.5
depth	40.6
weight	130 lb
X-ray generator	
manufacturer	Yxlon
model	Smart 300 HP
tube current	0.5 – 3.0 mA
tube voltage	20 – 300 kV
dimensions	30.5 (l) x 11.6 (dia) inches
weight	80 lb
X-ray controller	
manufacturer	Yxlon
model	Smart 583
power input	120V 15A AC
dimensions	18.3 (l) x 12.7 (w) x 6.1 (h) inches
weight	25 lb
power requirements	120V - 20A AC
Detector (linear detector array)	
manufacturer	Thales (or Thomson)
model	TH 9599 400
serial number	
digitization range	12 bits
Detector/housing Assembly	
dimensions	22.7 (l) x 6.1 (w) x 9.3 (h) inches
weight	45 lb
Rotation Stage	
dimensions	21.7 (l) x 14.5 (w) x 9.7 (h) inches
weight	90 lb
load capacity	150 lb
maximum object size	40 (h) x 13 (dia) inches
Electronics Box	
dimensions	8 (w) x 21.6 (d) x 19 (h) inches
weight	70 lb
power requirements	120V-10A AC
CT calibration phantom	
dimensions	12.7 (dia) x 39.5 (h) inches
weight	25 lb
Imaging scanner resolution	~ 1-2 mm
Scanning times for 1 meter tall object	generally object density dependent
	800 sec at 10Hz readout
	200 sec at 40 Hz readout
	133 sec at 60 Hz readout
Processing/imaging software, date, and version	
data acquisition (DRCT Digital Imager)	4.0.5
image reconstruction (DRCT Image Processing Interface)	V8-alpha
Programming software	
LabView	Motors, Data Acquisition
IDL, Matlab, Fortran	Data Processing

Appendix C

Detector Survey

Appendix C

Detector Survey

Linear (X-ray) Detector Arrays											
Manufacturer	Model	Detector technology	Scintillator	Length	Pixel pitch	Digitization	kV rating	Dynamic range	S/N ratio	Price	Comments
Envision	Segmented array	CMOS	GOS	18 in.	80 micron	12 bit	450			111K	Off axis design
Hamamatsu	C9750-18FC	Silicon photo diodes	GOS	18 in.	400 micron	12 bit	25-160			28K	Other lengths available, DC power, camera Link I/F option, auto dark correction, proprietary information, RS 422 or camera link options, $2K additional for frame grab. & dig. interface boards
X-Scan Imaging Corporation	XW8804-18/160	CMOS	GOS	18 in.	400 micron	16 bit	160		80 ADU	10.5K	Other lengths available
X-Scan Imaging Corporation	XH8804-18/320	CMOS	GOS	18 in.	400 micron	16 bit	320		80 ADU	30K	Other lengths available, off axis design, requires interface box
Detection Technologies	X-Scan iHE	Silicon photo diodes	$CdWO_4$	20 in.	400 micron	16 bit	160kev-5 MeV	> 8000		36K	No frame grabber needed, ethernet connection, other lengths, pixel pitches available,

Appendix D

Attributes of the Detection Technology Detector Array

Appendix D
Attributes of the Detection Technology Detector Array

General Characteristics	X-Scan 0.2iHE	X-Scan 0.4iHE	X-Scan 0.81HE	Thomson	Thales	VJ	Notes
X-ray tube voltage Vp range	100-600kVp	100-600kVp	100-600kVp	20-160kVp	20-160kVp	60-450kVp	
Scintillator material	$CdWO_4$	$CdWO_4$	$CdWO_4$	Gd_2O_2S	Gd_2O_2S	$CdWO_4$	
Scintillator thickness	3.15 mm	3.15 mm	3.15 mm	<< 1.0 mm	<< 1.0 mm	2.5 mm	
Active area lengths	410-820 mm	410-820 mm	410-820 mm	460.8 mm	460.8 mm	460.8 mm	
Pixel pitch (spacing)	0.2 mm	0.4 mm	0.8 mm	0.45 mm	0.45 mm	0.8 mm	
Number of elements	2048-4096	1024-2048	512-1024	1024	1024	576	
Pixel height (PD)	0.3 mm	0.6 mm	0.8 mm	0.60 mm	0.60 mm	1.6 mm	
Pixel width (PD)	0.1 mm	0.3 mm	0.7 mm	0.45 mm	0.45 mm	0.8 mm	
Pixel height (scintillator)	1.57 mm	1.57 mm	1.57 mm				
Pixel width (scintillator)	0.16 mm	0.25 mm	0.6 mm				
Maximum scanning speed	5-10 cm/s	20-26.7 cm/s	40-53.3 cm/s				
Minimum integration time	2.0-4.0 ms	1.5-2.0 ms	1.5-2.0 ms	5 ms	5 ms	5 ms	
Maximum integration time	128 ms	128 ms	128 ms	100 ms	100 ms	100 ms	
A/D resolution	16 bits	16 bits	16 bits	12 bits	12 bits	12 bits	
Electronic crosstalk of each channel	≤ 0.5%	≤ 0.5%	≤ 0.5%				
Dynamic range	> 8000	> 8000	> 8000				
Data digital interface	16 bits	16 bits	16 bits				
Interface	Ethernet	Ethernet	Ethernet				