INL/EXT-11-23455

Digital Radiography and Computed Tomography Project — Fully Integrated Linear Detector Array Status Report

Tim Roney
Robert Seifert
Robert Pink
Mike Smith

September 2011

Idaho National Laboratory

The INL is a U.S. Department of Energy National Laboratory
operated by Battelle Energy Alliance

INL/EXT-11-23455

Digital Radiography and Computed Tomography Project — Fully Integrated Linear Detector Array Status Report

Tim Roney
Robert Seifert
Robert Pink
Mike Smith

September 2011

Idaho National Laboratory
Idaho Falls, Idaho 83415

http://www.inl.gov

Prepared for the
Project Manager
Nonstockpile Chemical Materiel (PMNSCM), U.S. Army
and for the
U.S. Department of Energy
Under DOE Idaho Operations Office
Contract DE-AC07-05ID14517

This page intentionally left blank.

Digital Radiography and Computed Tomography Project — Fully Integrated Linear Detector Array Status Report

INL/EXT-11-23455
Revision 0

September 2011

Approved by:

Tim Roney
Project Manager

9/30/11
Date

Robert Seifert

9/30/11
Date

This page intentionally left blank.

EXECUTIVE SUMMARY

Idaho National Laboratory (INL) has been developing and deploying x-ray inspection systems for chemical weapons containers for the past 13 years under the direction of the Project Manager for Non-Stockpile Chemical Materiel (PMNSCM). In fiscal year (FY) 2011, funding was provided to advance the capabilities of these systems through the "Digital Radiography and Computed Tomography (DRCT) Product Improvement Plan (PIP)," funded by the PMNSCM. This report provides a summary of the work performed by INL to develop improved x-ray detectors for use in field-portable x-ray inspection devices used by the PMNSCM and supporting agencies for the inspection of chemical agents stored in a variety of containers. The primary goal for FY-11 was to fully integrate an advanced detector into one of the field-portable x-ray inspection systems.

The key accomplishments in FY-11 and proposed efforts for FY-12 are:

- Evaluation and integration of an advanced x-ray detector for the field-portable, single-munition x-ray inspection systems more commonly called digital radiography and computed tomography (DRCT) systems.

  The off-the-shelf detector from Detection Technology, Incorporated (DT), acquired in 2010 for testing and demonstration, was evaluated and integrated into the DRCT system referred to as DRCT-10.

  The DT detector had previously gone through preliminary testing for operability and image quality and appeared appropriate for the desired use. During the course of integration, the detector developed a system problem that required its return to the manufacturer in China. Turnaround time for the repair exceeded two months. During this time, INL initiated another search for a possible detector that could be acquired from a manufacturer closer to the United States. While other manufacturers were identified, it was determined that the DT detector hardware was superior to the others and the integration effort proceeded. Integration included both hardware mounting and interface, electronic modifications, and software to control data acquisition.

- Recommendation to the Operations and Maintenance organization within the PMNSCM for a detector upgrade for the field-portable x-ray inspection systems.

  Following assessment of the DT detector and competitor detectors, a recommendation was provided for a set of replacement detectors for the current suite of DRCT single-munitions x-ray inspection systems. At the present time, negotiations with DT are continuing to ensure the acquisition results in both high quality hardware and software from the vendor and long-term reliability and appropriate (i.e., immediate) support.

- Evaluation of other types of detectors for possible use in DRCT systems.

  There was minimal effort placed on this area in FY-11 with two exceptions. A competing linear detector array manufactured by X-Scan Corporation was evaluated but found to produce inferior image quality in comparison to the DT detector.

The DRCT Project is also interested in area detectors for DRCT systems. In FY-11, there were no tasks at INL that investigated area detectors. The DRCT Project made one visit to Sandia, Albuquerque, to witness operation of a high energy source (Betatron) where the detector used was a computed radiography area detector. Some area detector imaging also occurred at Bluegrass Chemical Activity using a Betatron and a newer computed radiography system. A preliminary review of these data was performed by George East (Draft Review of Blue Grass X-ray Images, George East, Shaw Environmental, Incoporated); however, in both cases, the circumstances were not appropriate to support a thorough study of the potential of computed radiography detectors for field imaging of munitions. At INL, the DRCT Project received a computed radiography system very late in the fiscal year. It is the plan of the DRCT Project to perform high energy testing of this system during FY-12.

- Other accomplishments and proposed new work.

  A recent driver for the DRCT work is the recognized need for improved imaging capability for large objects. The DRCT single-munitions inspection 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 current and future efforts is to expand the capability of DRCT systems to improve image results for larger high-density objects. Based on results obtained in FY-11, it appears viable to place a high energy x-ray generator, such as a betatron, on a single-munitions scanner with a corresponding high energy linear detector array. The DRCT Project plans to continue investigation and development of this imaging configuration in FY-12.

  There are additional minor improvements expected to occur with the new detector including the incorporation and use of new software from Detection Technology to support real time display modes and to minimize delays between data acquisition and image display. Modifications are also expected and will be addressed as experience is gained with the new detector in both the laboratory and field environments.

- A note on names.

  During this task, the DRCT Project looked at and will mention several x-ray detectors, including the following:

  1. Detection Technology, Incorporated, X-Scan 0.4iHE-512
  2. X-Scan Imaging Corporation XH-8804-006
  3. ScanX Discover Computed Radiography

  Despite the similarity in product and/or company names, it does not appear that any of these companies or products are related.

CONTENTS

FIGURES

This page intentionally left blank.

ACRONYMS

ADC	analog-to-digital conversion
CR	computed radiography
DT	Detection Technology, Incorporated
DRCT	digital radiography and computed tomography
FY	fiscal year
INL	Idaho National Laboratory
PMNSCM	Project Manager for Non-Stockpile Chemical Materiel

This page intentionally left blank.

Digital Radiography and Computed Tomography Project — Fully Integrated Linear Detector Array Status Report

1. INTRODUCTION

The field-portable digital radiography and computed tomography (DRCT) x-ray inspection systems developed for the Project Manager for Non-Stockpile Chemical Materiel over the past 13 years have used linear diode detector arrays from two manufacturers: Thomson and Thales. These two manufacturers no longer produce this type of detector. In the interest of ensuring the long-term viability of the portable DRCT single-munitions inspection systems and to improve the imaging capabilities, the DRCT Project has been investigating improved, commercially-available detectors. During fiscal year (FY) 2010, detectors were evaluated and one in particular, manufactured by Detection Technology, Incorporated (DT), was acquired for possible integration into the DRCT systems.

The proposed effort for linear detector array development in 2011 was stated as follows:

> **Detector Evaluation and Integration Task**: By the end of FY-10, the DRCT Project will have a new linear detector array from a vendor capable of providing detectors into the foreseeable future. The detector will be characterized and will be capable of serving as a replacement for the existing linear detector arrays on the current generation of DRCT systems. It will offer improved image quality due to a combination of improved sensitivity and dynamic range or contrast. There does not appear to be a detector on the market that matches identically the form factor and communications protocol of the existing DRCT detectors. Hence the detector acquired in FY-10 will be used to demonstrate the compatibility with the DRCT system but will require additional work in FY-11 to become fully integrated into one of the existing DRCT systems. Specifically, a permanent mount for the detector will be built and integrated into a DRCT platform and software compatible with the existing interactive DRCT platform to control data acquisition will be written. The integrated system will be field demonstrated.

The deliverable associated with the detector evaluation and integration task is a linear detector array fully integrated into a DRCT system.

By the end of FY-10, the DT detector had been selected for acquisition, received, and mounted on a DRCT gantry and initial tests of detector operability were initiated using the vendor-supplied software.

The remainder of this report describes the FY-11 progress towards a fully integrated detector on the DRCT single-munitions scanner platform.

Section 2 provides a brief overview of the field-portable, DRCT x-ray inspection system for single munitions. Section 3 describes the new DT detector and provides some comparisons with other detectors. Section 4 describes the characterization, integration, and testing of the new DT detector. Section 5 provides a summary.

2. FIELD-PORTABLE, DRCT SINGLE-MUNITIONS SCANNER

A description of the DRCT system and its current status was provided in the status report for the FY-10 work (INL/EXT-10-20231, “Digital Radiography and Computed Tomography (DRCT) Product Improvement Plan (PIP),” December, 2010). The most recent DRCT system is shown in Figure 1. Also provided in the report for the FY-10 work is a description of the DT linear detector array acquired in 2010. It is described more fully in Section 3.

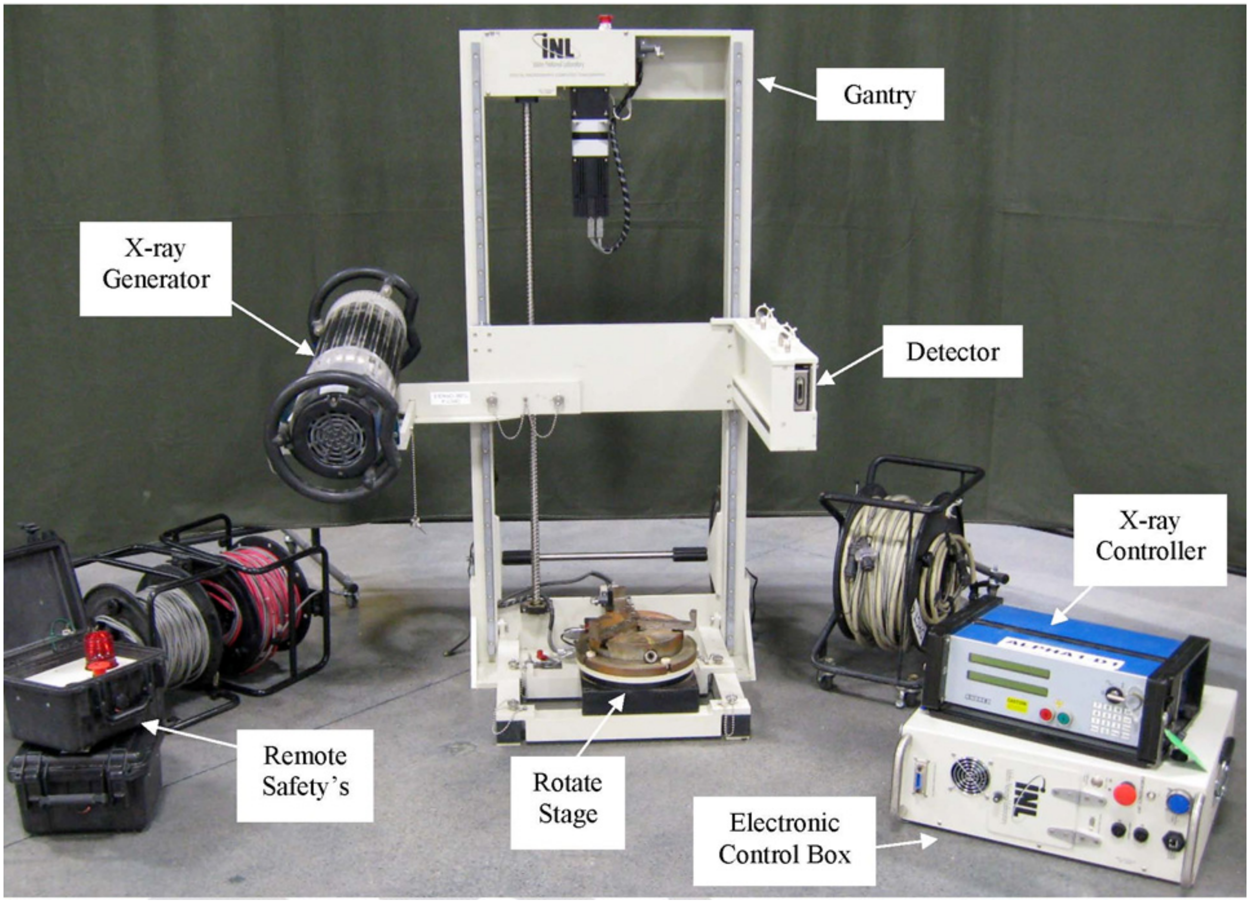

Figure 1. DRCT x-ray inspection system.

The DRCT single-munitions scanner shown in Figure 1 is in its third (current) generation with respect to developments in the gantry design, motors, and location/structure of the system electronics enclosure. The detector itself is still essentially derived from the first generation system. The original detector acquired from Thomson evolved somewhat in the electronics interface and was last produced by Thales but the detection component, a scintillation phosphor coupled to photodiodes, has not changed since the initial system development. Of the five operational DRCT systems currently in the PMNSCM inventory, two contain the original Thomson detectors and three contain the Thales detectors. A sixth detector failed in 2010. It was a component of DRCT-10. For the purposes of integration and testing of the new DT detector, DRCT-10 has been used as the platform.

3. DT LINEAR DIODE DETECTOR ARRAY

The DT X-Scan 0.4iHE-512 detector is a 1,280 element linear diode detector array (Figure 2). Each element is 0.25 mm in width, with a 0.4-mm overall pitch, yielding an overall detector length of 512 mm. This is longer than the current DRCT detectors, which are 1,024 elements by 0.45-mm pitch or 460.8 mm in length. Appendix A provides a comparison of the DT detector and the two linear detector arrays used on 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. The option exists to specify the depth of the scintillation element up to 10.0 mm; however, it adds considerable cost to a detector.

DETECTION TECHNOLOGY
X-Scan 0.4iHE-512

Figure 2. DT linear diode detector array acquired for DRCT single-munitions scanner detector integration task.

4. CHARACTERIZATION, INTEGRATION, AND TESTING OF DT LINEAR DIODE DETECTOR ARRAY ON DRCT GANTRY SYSTEM

The DT detector was acquired in FY-10. By the end of FY-10, the detector had been temporarily mounted on a DRCT gantry and a few images were acquired using DT-supplied software. No exposures were made at higher than 160kVp as the detector had not yet been properly shielded for higher energies. Thus during FY-10 it was only demonstrated that the detector was operational.

As previously mentioned, the goal for FY-11 was to have the DT detector fully integrated onto a DRCT gantry with electronics and software to allow for field operations. This goal has been met with the realization that some of the features of the data acquisition code for the older detectors could not be duplicated with the new DT detector given the current state of the vendor-supplied callable library routines. The two major differences are the inability to display a real time trace during image acquisition and an extended time delay between the end of image acquisition and the on-screen image display. Nevertheless, the new DT detector has been integrated and is capable of acquiring data in all modes previously enabled in the older detectors.

4.1 DT Detector Mechanical Integration

Following the initial tests in FY-10 of the DT detector, a permanent fixture was designed and developed to mount the DT detector on the DRCT-10 gantry. The DT detector is longer than the Thales/Thomson detectors and its cabling resides on the opposite end (nearest the gantry) in comparison to the Thales/Thomson detector cabling. Hence a new detector housing and mount were required (Figure 3).

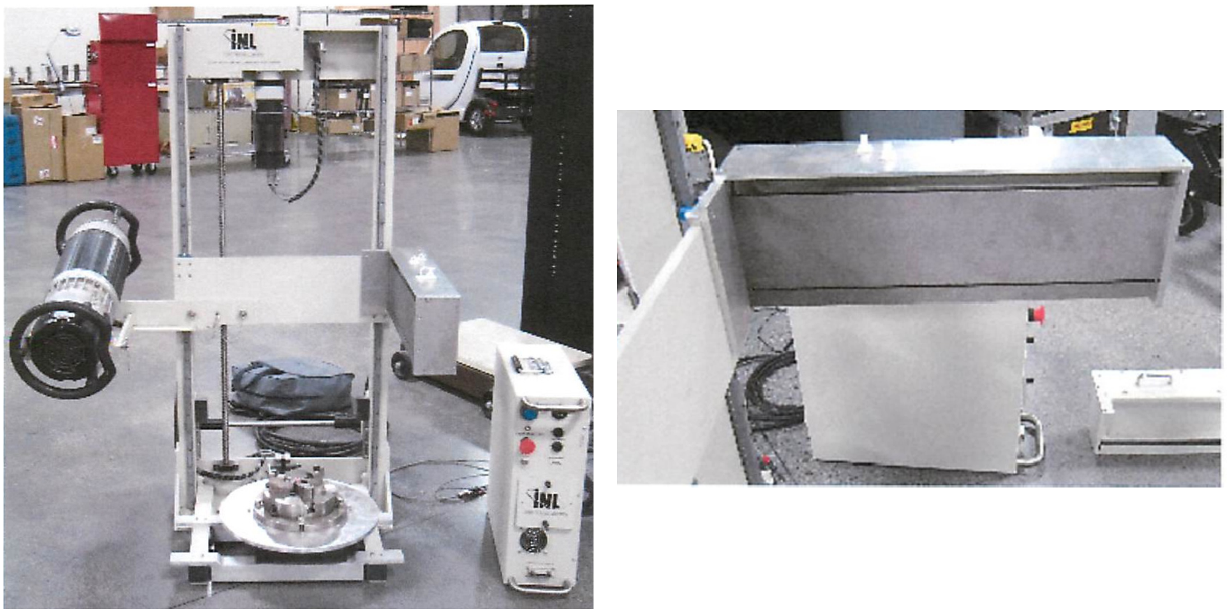

Figure 3. DRCT-10 system with DT X-Scan 0.4iHE-512 detector in aluminum/tungsten housing, mounted to gantry.

The new housing is made out of aluminum with a front side tungsten radiation shield/collimator. The radiation shield and collimator thickness is 0.300 in. (7.62 mm) and protects the detector electronics from x-radiation up to 360keV.

To accommodate the longer DT detector with connectors on the gantry end, the detector active region is now 1.578 in. (40 mm) further away from the x-ray generator. The detector array midpoint is also offset away from the DRCT gantry by 0.25 in. (6.4 mm) so that no active elements are blocked from radiation by the gantry's carriage plate.

The detector may be adjusted vertically to align the top edge of the active region with the bottom edge of the stationary radiation shield by loosening the four screws in the slotted holes on the back side of the housing and turning the two adjusting screws on the top. The collimator opening may be adjusted to any desired opening using the two screws on the bottom edge of the tungsten.

The original x-ray source spot-object-detector active region geometry had a source spot-detector distance of 36.914 in. (937.62 mm) and a source spot-object distance of 24.952 in. (633.78 mm) to allow for imaging a 12 in. (305 mm) diameter object. With the DT detector, the source spot to object distance is 38.490 in. (977.65 mm). This, along with the detector offset away from the gantry only allows for complete imaging of an 11 in. (279 mm) diameter object. With some additional moving of the generator and rotation stage to optimize the radiation geometry and to realign the source spot-object-detector axis, it should be possible to increase the object diameter that can be fully imaged to 14 in. (355.6 mm).

4.2 DT Detector Electrical Integration

The DT detector electrical connection consists of a multi-signal multi-channel cable. This cable is essentially two cables in one, one providing power to the detector and one providing communication and data transfer between a control personal computer and the detector. This is a simplified electrical interface compared to the older detectors. The new DT detector system performs all signal preprocessing steps and analog-to-digital conversions (ADC) within the detector module. The older detectors performed the ADC externally to the detector and required an additional electronics module.

Hardware changes to the DT detector involved fabrication of the above-mentioned cable and replacement of the existing Thales power supply. Subsequent DRCT electronic boxes can now employ smaller and lighter packaging.

4.3 DT Detector Software Integration

Software development for the DT detector consisted of developing protocols for detector setup, control, calibration and operation, image acquisition and display. Use of vendor-supplied software changed from the universal asynchronous receiver/transmitter protocol to the program language independent Microsoft Windows framework “ActiveX.”

Substantial rewrite of the “DRCT digital imager” interface was required to integrate the new ActiveX protocols with some loss of functionality. Great effort was taken to minimize, if not make transparent to the end user, the loss of this functionality. The most obvious loss is the inability to display a real time trace during data acquisition. This feature allows the operator to confirm in real time that data acquisition is occurring as expected. Discussions with DT have been initiated to have them provide software that will enable the real time trace. This fix will be a requirement for any future detector acquisitions. When the DT software is received, the “DRCT digital imager” will be modified to re-enable the real time trace. There is also an annoying delay between the time data acquisition completes and the image appears on the monitor. We are still working to understand, document and fix this problem.

4.4 DT Detector Characterization and Testing

Dynamic Range. The DT detector digitizes and records a 16-bit signal. The numerical range of values goes from 0 to 2^{16}-1 (65535). The true dynamic range of the detector must be less than this range due to various contributions of noise. The largest noise contributors are the dark current and read noise that are characterized by acquiring data when the x-rays are off. This image collected is referred to as a “dark” image (Figure 4). A “dark” image represents the average of 500 reads of the detector. As seen in upper panel in Figure 4, no element exceeds a variance of 2^3 (value of 8) (i.e., the detector exhibits less than 3 bits of dark/read noise). For the 16-bit ADC, the indication is that there will be greater than 13 bits of signal. During image correction, the lower trace is subtracted from each image line that is collected. The upper trace is only used for the diagnostic just described.

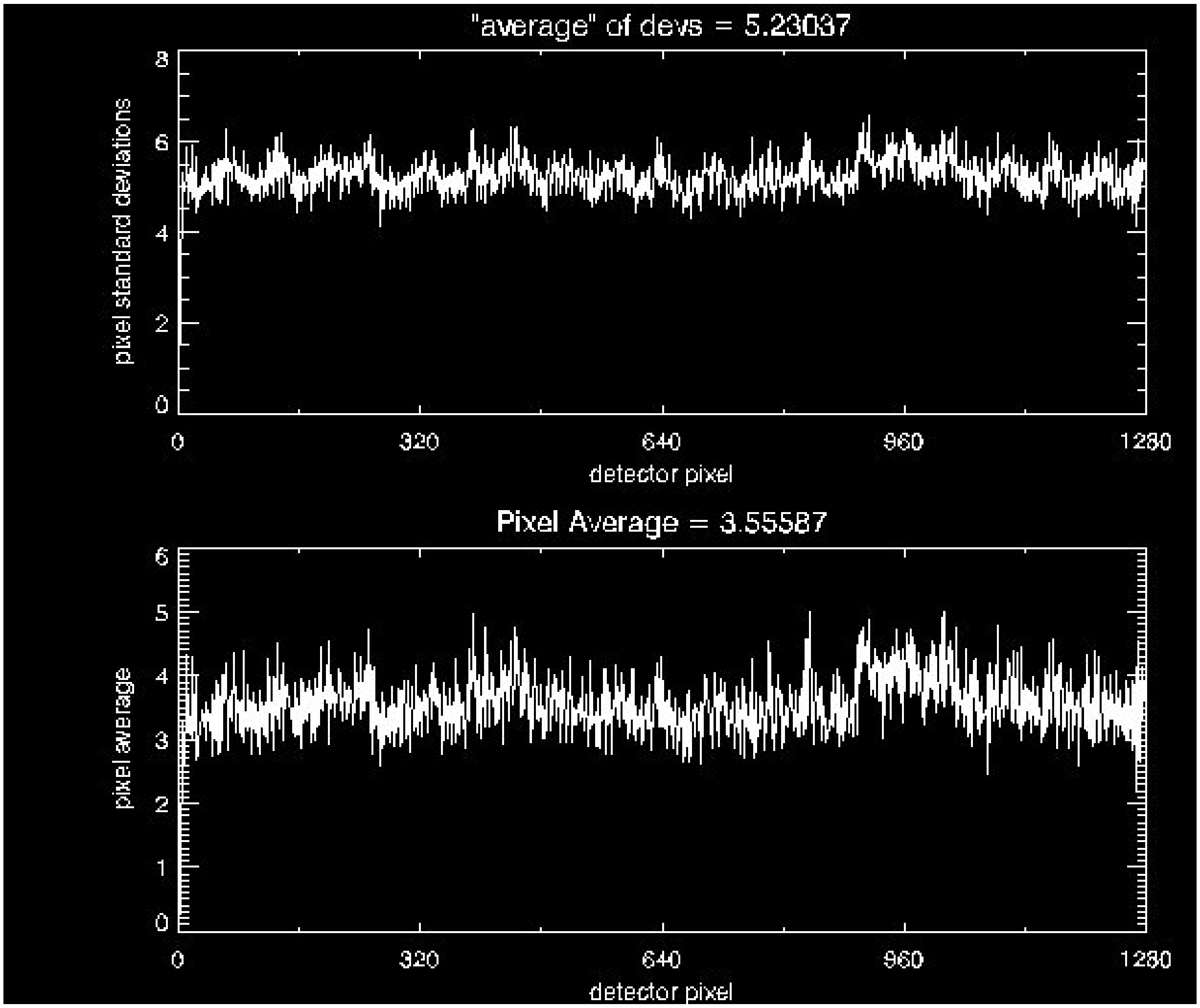

Figure 4. A "dark" image represents the average of 500 reads of the detector without any x-ray irradiation. The lower trace is the average readout. Note there are 1,280 image elements across the detector. The upper trace is the variance of each image element and represents the dark noise of the detector.

Saturation Value. For image correction purposes, the image collection protocol also suggests collection of an image with x-rays on but with no object blocking the field of view of the detector. This data is referred to as the "light" image. This image is collected with the x-ray source set to parameters that expose the detector to about 80% saturation. For statistical purposes, the software averages over 500 reads of the detector. In Figure 5, note that the average value in the lower trace is about 52,000, or roughly 80% of the full range of the ADC. Aside from its use in image correction, this image also serves to indicate bad, or nonresponsive pixels. It is clear from the light image that the detector is responding within an acceptable range.

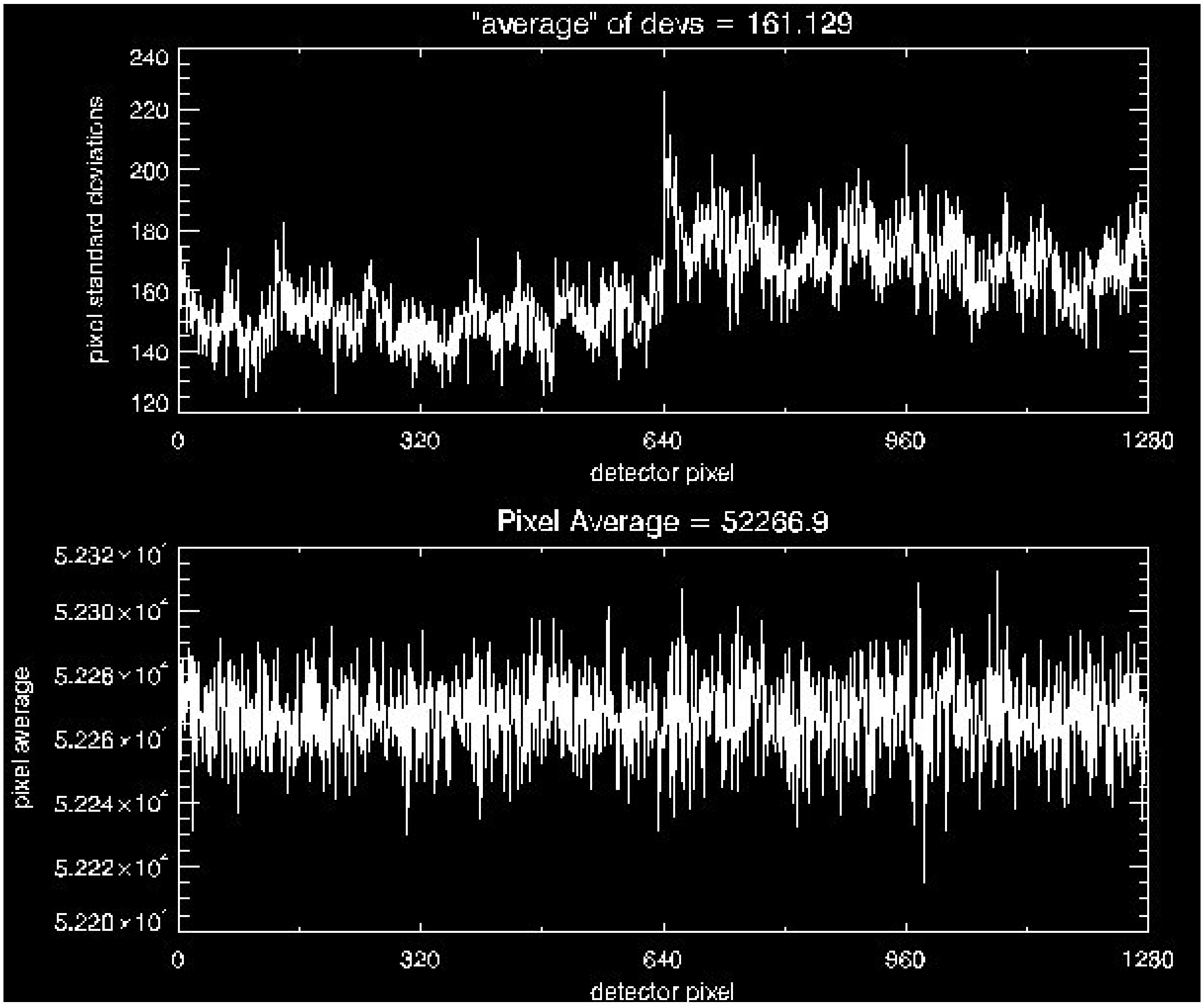

Figure 5. A “light” image represents the average of 500 reads of the detector when the x-ray irradiation nearly saturates the detector. For a 16-bit detector, the maximum value (at and above saturation) would be 2^{16}-1 or 65,535. The lower trace is the average readout. Note there are 1,280 image elements across the detector. The upper trace is the variance of each element. The lower trace is used to calibrate (normalize) the image data. The upper trace is only diagnostic.

Spatial Resolution. The DT detector spatial resolution has not yet been experimentally characterized. Based on a variety of images the DRCT Project has collected, it appears (qualitatively) that the DT detector performs spatially as well as the older detectors. There are two design reasons for the similarity. First, the Thales/Thomson detectors had a pixel pitch of 0.45 mm, while the DT detector has a pixel pitch of 0.40 mm. Thus, from a sampling perspective, the detectors are roughly equivalent. Second, the DT detector isolates individual adjoining pixels to minimize cross-talk between pixels. This is achieved by placing a small lead absorber between each discrete cadmium-tungstate scintillator and by painting a reflective material on the sides of the scintillation element to minimize light transfer between the photodiodes. Since the older detectors used a continuous sheet of gadolinium-oxysulfide as the scintillator, it was not possible to discretize the scintillation step. Note that since the DRCT systems acquire one horizontal line at a time and translate vertically, the spatial resolution along the horizontal line is detector dependent but the spatial resolution along the vertical is dependent on collimation, translate speed, and readout rate.

Image Acquisition. Figure 6 shows an image of a partially-filled 155-mm munition. From a qualitative perspective, there is little to be gained from showing this image because the limitation of imaging a 155-mm round with the DRCT system is due to the x-ray source. The DRCT Project has seen over the past several years that there is insufficient penetration power from the maximum output of 300kVp, 3mA of the Yxlon x-ray generator, which is the standard source for the DRCT gantry. As part of DRCT research and development in 2012, the DRCT Project plans to test the DT detector with higher powered x-ray sources. This will provide a better opportunity to evaluate its value for 155-mm munitions.

Figure 6. Radiograph of 155-mm munition using fully integrated DT detector. Due to the limited energy of the x-ray generator (300kVp), this image does not appear substantially better than those images acquired with the older detector.

Figure 7 provides a more interesting (at this stage of development) object for evaluation of the detector. For this test, an image was acquired of a steel step wedge. The thickness of the wedge ranges from 1/16 in. to 1 in. in 16 steps. When exposed at 200 kVp and 3 mA, the detector provides sufficient dynamic range (or contrast) such that all steps in the wedge are discernible. Two additional views verify this. The trace in Figure 7 shows an intensity step associated with each step in the wedge. Also, the histogram shows a spike for each intensity value associated with a step. Similar tests were performed with both the Thales/Thomson detector and one competitor's detector (X-Scan Imaging Corporation). Neither of these two detectors could be optimized in such a way to simultaneously show all steps in one image. For this particular imaging case, the DT detector was clearly superior.

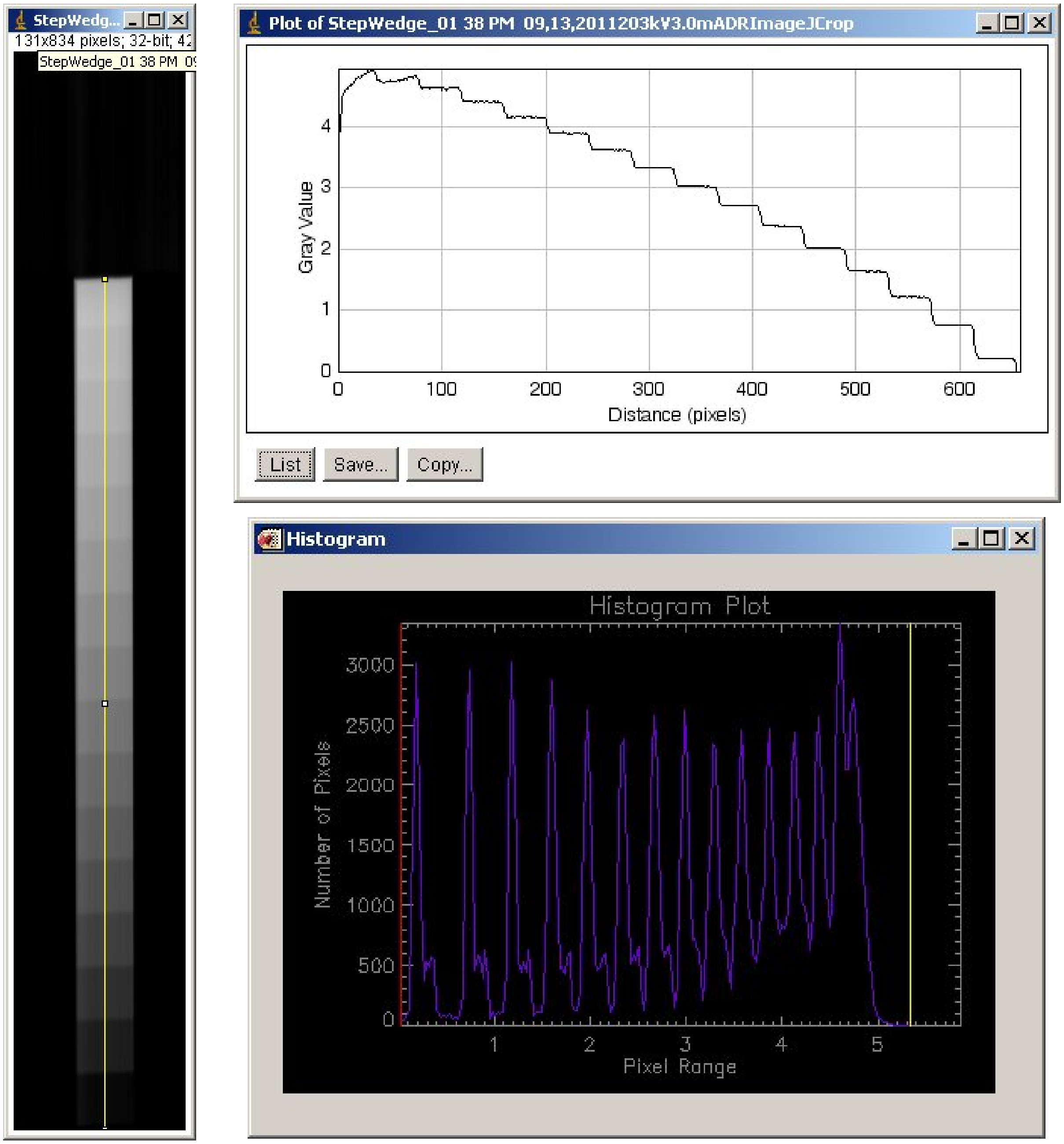

Figure 7. Image of steel step wedge with 16 steps acquired with the DT detector. The image is inverted (thicker towards the top) The radiograph clearly shows the reproduction of all 16 steps. For verification, a trace (yellow line) in the radiograph is plotted above. Each step in the trace represents a step in the radiograph (wedge). An alternative verification uses the histogram plotted above. In this display, each peak in the plot represents a step.

5. SUMMARY, CONCLUSION, AND PROPOSED FUTURE WORK

The DT X-Scan 0.4iHE-512 detector has been fully integrated into the DRCT-10 portable single-munitions scanner. Due to differences in the electronics associated with the control and data acquisition between the older Thales detectors and the DT detector and some limitations on software provided by the manufacturer, there will be some differences in the control panels and displays in the data acquisition software. These differences are minimal and will not affect the image acquisition capabilities or the image quality of the results. The DRCT Project has uncovered two other minor problems that have yet to be successfully addressed:

1. Because the DT detector uses an ethernet protocol for commands and data transfer to the computer, the DRCT Project has found a conflict between the detector ethernet address and the ethernet communications between the host computer (in the DRCT electronics box) and the remote laptop computer.
2. When transferring files between the data acquisition software and the data processing and display software, the aspect ratio of the image is interpreted incorrectly. This can lead to images appearing to be too wide or narrow.

The DRCT Project is working on corrections to both these problems and expects them to be resolved soon.

A recommendation has been provided to Mr. Stacey Barker (Idaho National Laboratory) and Mr. Rusty Fendick (Project Manager for Non-Stockpile Chemical Materiel) for replacement of the existing set of linear detectors arrays currently housed on the DRCT single-munitions scanners. The recommendation is to acquire the DT X-Scan 0.4iHE-512 detector that has been used in this task for each DRCT system. In addition, it is worth considering the acquisition of one DT detector as recommended but with a thicker scintillation crystal to enable more efficient detection at much higher energies than are currently used on the DRCT systems. Based on results using a 2.5MeV Betatron with other linear detector arrays, there is high potential for greatly improved images of thick metal objects with a combination of high energy and DT detectors with longer scintillation crystals. The effort to confirm this notion is ongoing and will be part of the 2012 DRCT Project tasks.

DT produces a superior detector with respect to the hardware and potential image quality. Unfortunately, DT software, software support, and return/repair process has been found to be inferior to other vendors. In terms of understanding the base software provided by DT and using it to develop the familiar data acquisition interface for the DRCT systems, the problems have largely been overcome by an intensive effort from our software engineer for data acquisition, Mike Smith. Since the data acquisition software that utilizes the vendor-supplied routines has been largely completed, this inadequacy should not present a problem in the future. However, with respect to ongoing support and turnaround on repair, INL has made it clear to DT that, if the multiple detector acquisition was to occur, they need to be much more responsive to our needs. DT responded enthusiastically and indicated that they will take steps to ensure good support to the needs of INL in the future. This bodes well for a long-term relationship with DT. INL is also likely to consider DT for future detector acquisition for larger detectors capable of handling higher energies.

There is long-term interest in area detectors for DRCT systems. At INL, the DRCT Project received a computed radiography system very late in the fiscal year. It is proposed to perform high energy testing of this system during FY-12.

A recent driver for the DRCT work is the recognized need for improved imaging capability for large objects. The DRCT single-munitions inspection 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 current and future efforts is to expand the capability of DRCT systems to improve image results for larger high-density objects. Based on results obtained in FY-11, it appears viable to place a high energy x-ray generator, such as a betatron, on a single-munitions scanner with a corresponding high energy linear detector array. The DRCT Project plans to continue investigation and development of this imaging configuration in FY-12.

There are additional minor improvements expected to occur with the new detector including the incorporation and use of new software from Detection Technology to support real time display modes and to minimize delays between data acquisition and image display. Modifications are also expected and will be addressed as experience is gained with the new detector in both the laboratory and field environments.

This page intentionally left blank.

Appendix A

Attributes of Detection Technology, Incorporated, Detector Array

This page intentionally left blank.

Appendix A

Attributes of Detector Arrays

General Characteristics	X-Scan 0.2iHE	X-Scan 0.4iHE	X-Scan 0.81HE	Thomson	Thales	VJ	X-Scan XH8804
X-ray tube voltage Vp range	100-600kVp	100-600kVp	100-600kVp	20-160kVp	20-160kVp	60-450kVp	20-320kVp
Scintillator material	$CdWO_4$	$CdWO_4$	$CdWO_4$	Gd_2O_2S	Gd_2O_2S	$CdWO_4$	Gd_2O_2S
Scintillator thickness	3.15 mm	3.15 mm	3.15 mm	<<1.0 mm	<<1.0 mm	2.5 mm	<<1.0 mm
Active area lengths	410-820 mm	410-820 mm	410-820 mm	460.8 mm	460.8 mm	460.8 mm	152.4-609.6 mm
Pixel pitch (spacing)	0.2 mm	0.4 mm	0.8 mm	0.45 mm	0.45 mm	0.8 mm	0.4
Number of elements	2,048-4,096	1,024-2,048	512-1,024	1,024	1,024	576	384-1536
Pixel height (PD)	0.3 mm	0.6 mm	0.8 mm	0.60 mm	0.60 mm	1.6 mm	0.60 mm
Pixel width (PD)	0.1 mm	0.3 mm	0.7 mm	0.45 mm	0.45 mm	0.8 mm	0.36 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	16 bits
Electronic crosstalk of each channel	≤0.5%	≤0.5%	≤0.5%				
Dynamic range	>8,000	>8,000	>8,000				
Data digital interface	16 bits	16 bits	16 bits				
Interface	Ethernet	Ethernet	Ethernet				

NOTE: *The first three columns are detectors produced by Detection Technology, Inc. The Thomson/Thales columns represent the detectors currently used in the DRCT systems. The last two columns show information from two other manufacturers of detector arrays.*