Site Acceptance Testing Procedure for ISA MicroCT System

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Work performed for the
Science & Technology Directorate of the
Department of Homeland Security
Statement of Work
PR RSEN-08-00066

December 31, 2013
Version 1.0
LLNL-TR-649194
IM# 768396

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This work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.

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1/06/2014

1 Overview

This document details the site acceptance test for the ISA x-ray micro computed tomography (MCT) system. This test is intended to verify the safe and proper operation of the Yxlon and LLNL provided components (enclosure, motorized staging, and x-ray source, detector, etc.). The specifications for this system are outlined below:

Imaging Performance	
Pixel Pitch w/ Mag	160 µm x 160 µm
Field of View w/ Mag	330 mm x 330 mm
SNR	> 10^2
Motion Control System	
Newport XPS 6-Axes Newport RV160PP Rotation stage Newport IMSCC 600 Translation Stage, (1 in-system, 1 backup) Newport MTM PP 100mm Translation Stage, (2 backup)	
Detector System	
Detector	Perkin Elmer XRD 1620 AN14 CS 16” 200 µm pixel
X-Ray Source (Yxlon D11)	
Max Voltage	450 kV
Max Current	1.6 mA / 3.3 mA
Min Spot Size	400 um / 1.0 mm
Target Material	Tungsten
Output Window	5.0 mm Beryllium
Computer	
Dell Optiplex Computer 755	
Duel 20" Ultrasharp Flat Panel Monitors Intel Core 2 Duo Processor E6700 w/ 4 GB DDR2 RAM (minimum) 160GB Internal Hard Drive Two 500 GB portable hard drives	
Enclosure	
Emergency Stops & Warning Lights Radiation ALARA Limits Fully Interlocked	

2 Enclosure and X-ray Components

LLNL has designed the internal components to acquire accurate, precise, and repeatable digital radiographs and computed tomographies. Yxlon has designed the enclosure to provide a stable environment for the components while maximizing user safety. The acceptance test will require that the position and orientation of each component must match the layout diagrams provided by LLNL, and will require the safe and stable demonstration of the x-ray source.

> **Note**: The Site Acceptance Test (SAT) is designed to test the safe and correct operation of Yxlon and LLLNL provided components. Requirements for the SAT are marked with an asterisk (*). Unmarked items, e.g. *MTF*, may or may not be measured and will not be used for SAT validation.

	Criteria	FAT	SAT
	Verify component present		
1	Panel holder	*	*
2	Carousel	*	*
3	Slit collimator	*	*
4	Source pre-collimator	*	*
5	Source alignment collar	*	*
6	Source	*	*
7	High voltage generators & control	*	*
8	Cooling tubes and heat exchanger	*	*
	Demonstrate cabinet		
9	Left maintenance door operation	*	*
10	Right maintenance door operation	*	*
11	Back maintenance door operation	*	*
12	Sample door power assist op.	*	*
13	No weld defects, sharp edges…	*	*
14	Electrical distribution box	*	*
	Demonstrate safety systems		
15	Emergency Stop	*	*
16	Radiation warning light	*	*
17	Door interlock	*	*
18	Radiation emission < 0.25 mR/hr	*	*

	Demonstrate source motion		
19	Manipulator vertical range: 21” (tube mount permitting)	*	*
20	Manipulator horizontal range: (tube mount permitting)	*	*
21	Rotatability about vertical	*	*
22	Rotatability about central ray	*	*
23	Rotatability about transverse	*	*
	Demonstrate source		
24	System warmup to max kVp	*	*
25	Large spot @ max kVp & current operation for 30 min	*	*
26	Large spot @ max kVp & current spot size < 1.0 mm	*	*
27	Small spot @ max kVp & current operation for 30 min	*	*
28	Small spot @ max kVp & current spot size < 0.4 mm	*	*

3 Motion Control System Test

The motion control package consists of several motorized stages and a motion controller designed to work with the LLNL acquisition software. The motion control package will be demonstrated in final configuration using the provided software package. The tests to be conducted will include:

	Criteria	FAT	SAT
	Verify component present		
29	Newport XPS Motion Controller	*	*
30	XPS-DRVO3 for IMS600LM	*	*
31	XPS-DRVO1 for RV160PP	*	*
	Verify range of motion		
32	IMSCC 600: 600 mm	*	*
33	RV160PP: 360 degrees	*	*
34	Spare IMSCC 600: 600 mm	N/A	N/A
35	Spare MTM 100PP: 100 mm	N/A	N/A

4 Computer and Data Acquisition

LLNL will provide the software suite that coordinates all of the data acquisition, tomographic data collection and 2D image processing functions of the MCT under a pair of software packages. The acquisition software, LLNL DRCT, provides a user interface for coordinating the motion control system and image acquisition from the flat panel detector [Benson]. The image processing package, IMGREC, provides a suite of image processing, analysis, and reconstruction routines for both digital radiography and computed tomography datasets [Schneberk].

	Criteria	FAT	SAT
	Verify minimum computer specs for data acquisition machine		
36	Dual 20" Flat Panel Monitors	*	*
37	Core 2 E8600 Processor	*	*
38	4 GB RAM	*	*
39	160 GB internal storage	*	*
40	Windows 7, 32-bit	*	*
	Verify minimum computer specs for CT reconstruction machine		
41	Dual 20" Flat Panel Monitors	*	*
42	Core 2 E8600 Processor	*	*
43	4 GB RAM	*	*
44	160 GB internal storage	*	*
45	Windows 7, 64-bit	*	*
	Demonstrate Software		
46	Acquisition of single DR	*	*
47	Acquisition of CT	*	*

5 Imaging Performance

The imaging characteristic of the system may or may not be measured during Site Acceptance depending on available time. Unless otherwise noted all data is acquired using the techniques in appendix A.

5.1 Defining Image Metrics and acquisition parameters

Image noise in a single projection determines the ultimate dynamic range and through the SNR, it dictates many experimental parameters. In this context, image noise includes contributions from readout noise, dark current and electrical pickup from the x-ray source. Since the dark current and electrical noise increase linearly with acquisition time while the readout noise is fixed, one can separate the relative contributions of each parameter by varying the integration time. The combined noise will be measured

in the detector center by taking the standard deviation of a patch sufficiently large to accurately estimate the local statistical properties.

The signal to noise ratio (SNR) measures the peak contrast relative to the noise, and is defined as the difference between the mean of two signals divided by the square root of the variance sum:

$$\mathrm{SNR} = \frac{S_1 - S_2}{\sqrt{\sigma_1^2 + \sigma_2^2}}$$

where S and σ are the mean and standard deviation of two areas that are well separated from any transition region.

The resolution of the system will be validated by calculating the Modulation Transfer Function using a Radiographic MTF edge. To reduce noise in the MTF a minimum of 10 lineouts should be averaged. The edge should be aligned to the detector grid to within $1/10^{th}$ over the averaged region. To compute the MTF, the derivative of the average edge response will be calculated, resulting in what is called the line-spread function. The Fourier transform of the line-spread function is the MTF.

The MTF will be measured using lineouts taken at several angles relative to the horizontal axis: 0°, 45°, 90°, and 135°.

A stable x-ray system is required for precision computed tomography. The unobstructed background will vary characteristically during the source warm-up, during steady state, and with detector afterglow following shutoff. To test both the brightness and spectral dependence, a series of 1 second DR images will be acquired over a 75-minute period. A Copper strip will be placed in the center of the detector such that it will be imaged through the top slit. The acquisition will begin with the source off. After two minutes, the source will turn on and remain on for 60 minutes. At 62 minutes, the source will turn off and data will be acquired for another 13 minutes. The experiment will be repeated without the x-ray source on to check dark noise changes over time.

5.2 High energy measurements

The following measurements are taken using the High Energy settings: 2.0 mm Al & 2.0 mm Cu filtering with the source operating at: 160 kV & 4.35 mA.

	Criteria	FAT	SAT
	Reference Stability		
48	RMS fluctuations in I_0, Minutes 5 – 62		*
49	RMS fluctuations in dark step Minutes 5 – 62		*
	HE: Signal to Noise		
50	300 ms integration		*
51	800 ms integration		*
52	1200 ms integration		*
	HE: Resolution		
53	2D MTF		
54	3D MTF (use CT acq. Settings)		
	HE: After glow		
55	Decay ratio after 1 second		
56	Decay ratio after 10 minutes		
	HE: Dark Current (noise)		
57	300 ms integration		*
58	800 ms integration		*
59	1200 ms integration		*

5.3 Low energy measurements

The following measurements are taken using the Low Energy settings: 2.0 mm Al source filtering only, source is 100 kV & tube current will be adjusted to acquire greater than 2/3 well depth at 1.0 second integration.

	Criteria	FAT	SAT
	Reference Stability		
60	RMS fluctuations in I_0, Minutes 5 – 62		*
61	RMS fluctuations in dark step Minutes 5 – 62		*
	HE: Signal to Noise		
62	300 ms integration		*
63	800 ms integration		*
64	1200 ms integration		*
	HE: Resolution		
65	2D MTF		
66	3D MTF (use CT acq. Settings)		
	HE: After glow		
67	Decay ratio after 1 second		
68	Decay ratio after 10 minutes		
	HE: Dark Current (noise)		
69	300 ms integration		*
70	800 ms integration		*
71	1200 ms integration		*

6 References

SCHNEBERK Schneberk, D., *Imgrec User Guide: CT Pre-processing, Reconstruction, and Image Processing and Inspection Tools*, Version 10, Lawrence Livermore National Laboratory, March 1, 2010

BENSON Benson, S., *Digital Radiography and Computer Tomography (DRCT)*, Lawrence Livermore National Laboratory, LLNL-TM-649120, February 2014