Summary Statistics for Homemade "Play Dough" Data Acquired at LLNL

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Executive Summary

Measured Density: $1.31 g/cm^3$		X-ray beam energy and source filter material(s)			
Parameter		100kVp (Al)	160kVp (Al)	160kVp (AlCu)	300kVp (Cu)
LAC	*Mean Measured LAC ($LMHU_D$)*	2732	2186	1447	1232
	Standard Deviation (% of Mean)	17%	14%	9%	8%
	Entropy	7.39	7.00	6.19	5.96
	Modeled LAC ($LMHU_D$)	(na)	(na)	(na)	(na)
	Difference Between Model & Mean	(na)	(na)	(na)	(na)
Z_{eff}	*From the mean measured LAC*	10.1			
	From the modeled LAC	(na)			

Table 1. *First-order statistics of the x-ray linear attenuation coefficient (LAC) in homemade "Play Dough" ™ and the estimated value of Z_{eff}.*

Using x-ray computerized tomography (CT), we have characterized the x-ray linear attenuation coefficients (LAC) of a homemade Play Dough™-like material, designated as PDA. [1, 2] Table 1 gives the first-order statistics for each of four CT measurements, estimated with a Gaussian kernel density estimator (KDE) analysis. [3]. The mean values of the LAC range from a high of about 2700 $LMHU_D$[1] at 100kVp to a low of about 1200 $LMHU_D$ at 300kVp. The standard deviation of each measurement is around 10% to 15%of the mean. The entropy covers the range from 6.0 to 7.4. Ordinarily, we would model the LAC of the material and compare the modeled values to the measured values. In this case, however, we did not have the detailed chemical composition of the material and therefore did not model the LAC. Using a method recently proposed by Lawrence Livermore National Laboratory (LLNL), [4] we estimate the value of the effective atomic number, Z_{eff}, to be near 10.

LLNL prepared about 50mL of the homemade "Play Dough" in a polypropylene vial and firmly compressed it immediately prior to the x-ray measurements. We used the computer program IMGREC to reconstruct the CT images. The values of the key parameters used in the data capture and image reconstruction are given in this report. Additional details may be found in the experimental SOP [1] and a separate document.[2] To characterize the statistical distribution of LAC values in each CT image, we first isolated an 80% central-core segment of volume elements ("voxels") lying completely within the specimen, away from the walls of the polypropylene vial. All of the voxels within this central core, including those comprised of voids and inclusions, are included in the statistics. We then calculated the mean value, standard deviation and entropy for (a) the four image segments and for (b) their digital gradient images. (A digital gradient image of a given image was obtained by taking the absolute value of the difference between the initial image and that same image offset by one voxel horizontally, parallel to the rows of the x-ray detector array.) The statistics of the initial image of LAC values are called "first order statistics;" those of the gradient image, "second order statistics."

[1] $LMHU_D$: "LLNL modified Hounsfield units with respect to Delrin." To obtain the LAC in $LMHU_D$ for some material at a specific energy, one divides the LAC of that material (in units of reciprocal mm) for that energy by the LAC of Delrin for 160kVp (also in reciprocal mm) and multiplies the result by 1400. The result is a dimensionless value. The LAC of Delrin used to normalize all LAC values in this report is the value measured with an x-ray energy of 160kVp with combined aluminum and copper filters.

Summary of PDA X-ray Statistics

Report Date: 3/12/2010

Author: W. Travis White, III — LLNL
Typed or Printed Name — *Organization*

QA: Robert D. Huber — LLNL
Typed or Printed Name — *Organization*

Explosive ID(s): PDA, Homemade "Play Dough"™

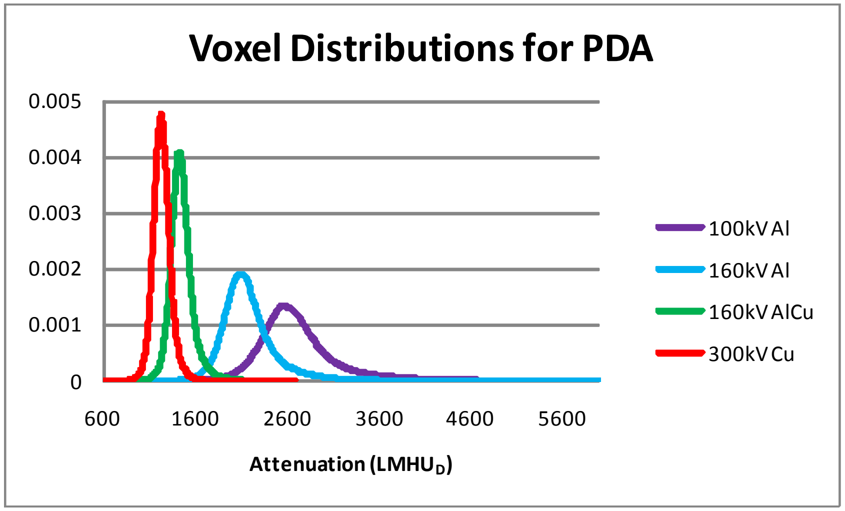
Source			Collimator	Sample Preparation	X-ray Measurement	Linear Attenuation Coefficient (LAC)		
Bias (kV)	**Filters** Material	Thickness	**Number of slits**	**Date**	**Date**	**Statistic**	**1st order**	**2nd order**
100	Al	1.943 mm	2	02/18/2010	02/18/2010	**Mean** **Std. Dev.** **Entropy** **Calculated**	2732 468 7.39 (na)	236 238 6.50 (na)
160	Al	1.943 mm	2	02/18/2010	02/18/2010	**Mean** **Std. Dev.** **Entropy** **Calculated**	2186 306 7.00 (na)	157 152 6.09 (na)
160	Al Cu	1.943 mm 1.905 mm	2	02/18/2010	02/18/2010	**Mean** **Std. Dev.** **Entropy** **Calculated**	1447 128 6.19 (na)	79 67 5.38 (na)
300	Cu	2.972 mm	2	02/18/2010	02/18/2010	**Mean** **Std. Dev.** **Entropy** **Calculated**	1232 97 5.96 (na)	70 55 5.23 (na)
Z_{eff}						**Z_{eff} based on measured LAC**	10.13	
						Z_{eff} based on calculated (modeled) LAC	(na)	

Table 2. *Key statistics for x-ray measurements of Linear Attenuation Coefficient (LAC).*

Comments:

Data Shipped to TSL **TBD** — TBD
Date — ***Name of Sender***

SUPPLEMENTAL ANALYSIS



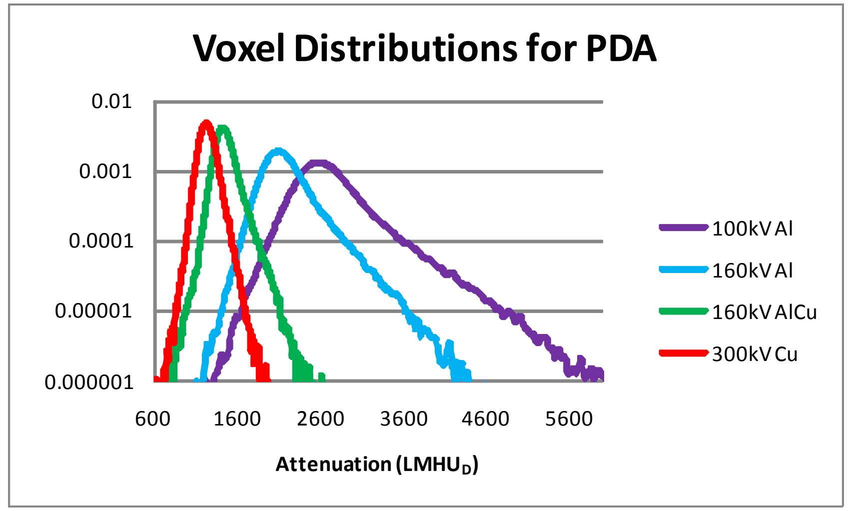


Figure 1. *KDE histograms of values of the linear attenuation coefficient (LAC) for PDA for four x-ray source settings (linear plots – left; semi-log plots – right).*

Comments/Observations on Histograms: These histograms are made using 150 µm voxels

Reference Specimens

	graphite	*ethanol*	*Delrin*	*water*	*Teflon*	*aluminum*
100kV (Al) Mean	1826	1080	1901	1483	3195	7525
100kV (Al) Std Dev	87	58	86	57	98	136
160kV (AlCu) Mean	1458	844	1400	1044	1997	3089
160kV (AlCu) Std Dev	61	44	56	45	60	72

Table 3. *Linear attenuation coefficients (LMHU$_D$) of six reference materials as measured simultaneously with PDA.*

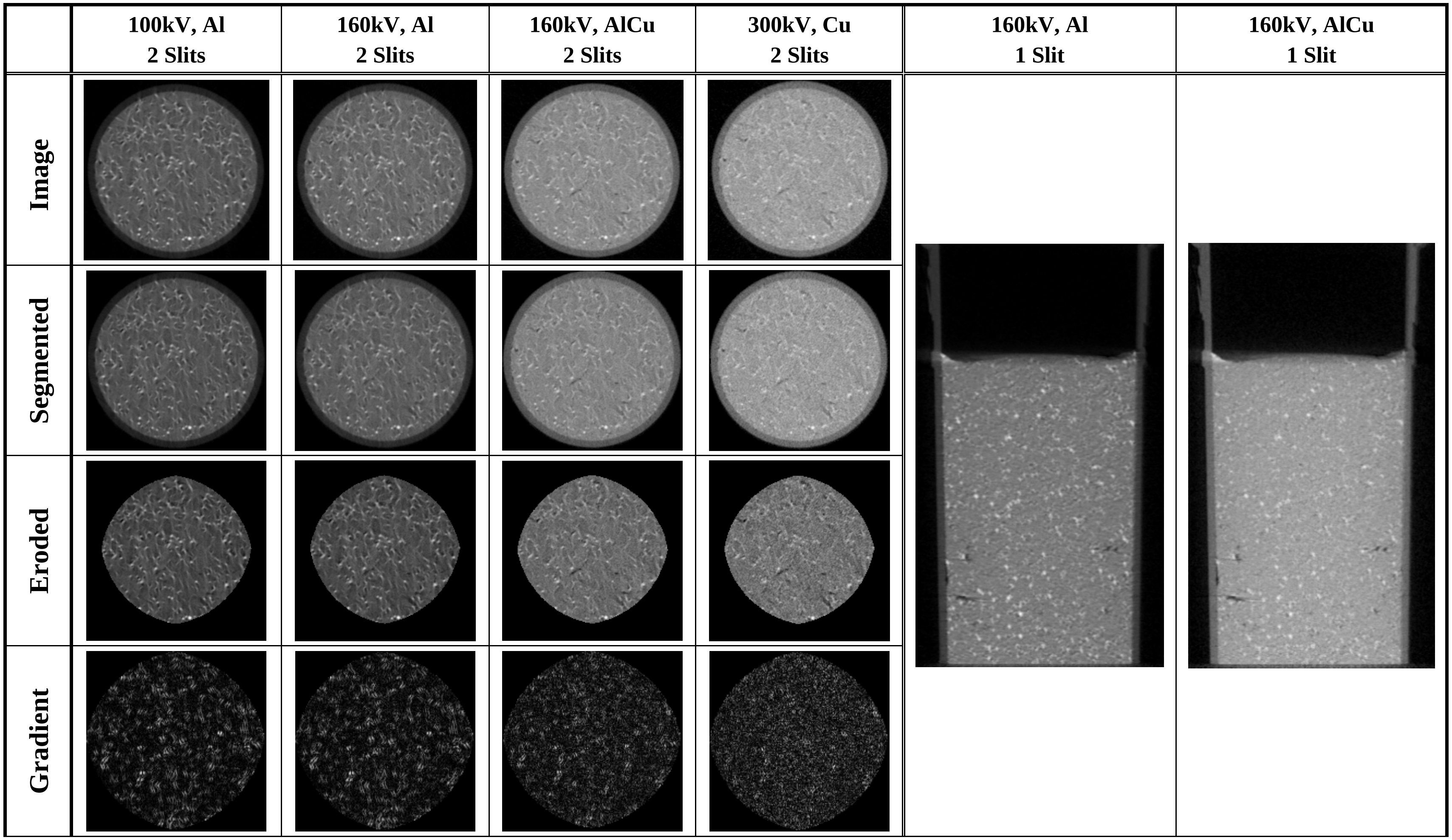


Figure 2. *X-ray slice images with 150μm x 150 μm x150 μm voxels.* *Raw data (top row), first-order segmented images (second row), eroded images* **(***third row) used to calculate first order statistics. Fourth row, difference or gradient image used for second-order statistics. Images not to scale.*

Comments/Observations on Appearance of Sample (texture, color, other): ____

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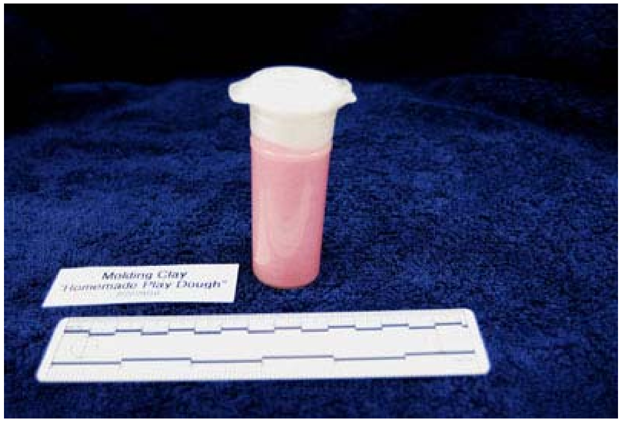
Specimen Preparation

1. **Persons responsible:** Rich Whipple and Adriana Martz
2. **Date/time:** 02/23/2010
3. **Location:** LLNL
4. **Identifier:** PDA, Homemade "Play Dough"
5. **Preparation procedure:** Mix all ingredients (1 c flour, ¾ c water, ½ c salt, 1 T oil, 2 t cream of tartar, glitter watercolor), and cook over medium heat, stirring constantly until it can be made into a ball. Cool and knead for a few minutes. Store in a zip lock bag or airtight container.
6. **Container:** Polypropylene vial with attached snap cap, p/n 09-341-75A, Fisher Scientific
7. **Nominal Measured Density:**[1] Average density of as-x-rayed specimen = 1.31 g/cc
8. **Image of Sample:**



9. **Observations:**

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[1] Ratio of mass and volume of the specimen in the container, including cracks and voids.

CT System Configuration

1. Scan Location Site: LLNL HEAF
2. Source: Yxlon D09 450 kV Tube; Mfr. Catalog Number: 9421-172-33503; S/N 61-0971
3. Detector: Thales Flashscan 33 with Lanex Fine Gadolinium Oxysulfate Scintillator Screen; s/n 392177
4. Rotation control system. Controller: Newport Model ESP7000 SN: 1250
5. Carousel: LLNL 2-tray, 7" Dia.
5. Data capture computer: Dell DHM/J4271

CT Scan Parameters

1. Scan Geometry:[1] SOD (mm): 1102 ODD (mm): 286
   Number of positions: 400 Angular Range: 200° Angular Increment: 0.5°
2. Number of Frames averaged per Image: 4
3. Integration time per frame: See p 7.

[1] Distances are those recorded in the .sct file for this experiment and are the values used in image reconstruction.

File Storage Locations for X-ray Data

Specimen

Root Data Path: /Working /TP35_Industrial_CT_of_HME/LLNL/None/HEAFCAT/None/PDA_100223 /{sub directory}/Raw_Data

Specimen ID	Date	Radiographer	Slits	kVp	mA	Al Filter (mm)	Cu Filter (mm)	Integration *dpix* Setting [time/frame (s)]	{sub directory}	File Name
PDA	100223	Morales	2	100	1.1	1.943	0	10 [3.2s]	/PDA_100Al	PDA_100Al_*nn*.sdt[1]
	100223	Morales	2	160	0.7	1.943	0	5 [2.3s]	/PDA_160Al	PDA_160Al_*nn*.sdt
	100223	Morales	2	160	4.35	1.943	1.905	8 [2.8s]	/PDA_160AlCu	PDA_160AlCu_*nn*.sdt
	100223	Morales	2	300	2.3	0	2.972	4 [2.1s]	/PDA_300Cu	PDA_300Cu_*nn*.sdt
	100223	Morales	1	160	0.7	1.943	0	5 [2.3s]	/PDA_160Al 1slit	PDA_160Al 1slit _*nn*.sdt
	100223	Morales	1	160	4.35	1.943	1.905	8 [2.8s]	/PDA_160AlCu1slit	PDA_160AlCu1slit _*nn*.sdt

Dark current, mid-range, bright field and I_o

Root Data Path: /Working /TP35_Industrial_CT_of_HME/LLNL/None/HEAFCAT/None/PDA_100223 /{sub directory}/Raw_Data

Slits	kVp	Filter	{sub directory}	Dark Image File Name	Mid-Brightness Image File Name	Max Brightness Image File Name	*Io* Image File Name
2	100	Al	/PDA_100Al	PDA_100Aldrk.sdt	PDA_100Almid.sdt	PDA_100Allit.sdt	PDA_100Albak.sdt
2	160	Al	/PDA_160Al	PDA_160Aldrk.sdt	PDA_160Almid.sdt	PDA_160Allit.sdt	PDA_160Albak.sdt
2	160	AlCu	/PDA_160AlCu	PDA_160AlCudrk.sdt	PDA_160AlCumid.sdt	PDA_160AlCulit.sdt	PDA_160AlCubak.sdt
2	300	Cu	/PDA_300Cu	PDA_300Cudrk.sdt	PDA_300Cumid.sdt	PDA_300Culit.sdt	PDA_300Cubak.sdt
1	160	Al	/PDA_160Al1slit	PDA_160Al1slitdrk.sdt	PDA_160Al1slitmid.sdt	PDA_160Al1slitlit.sdt	PDA_160Al1slitbak.sdt
1	160	AlCu	/PDA_160AlCu1slit	PDA_160AlCu1slitdrk.sdt	PDA_160AlCu1slitmid.sdt	PDA_160AlCu1slitlit.sdt	PDA_160AlCu1slitbak.sdt

[1] *nn* - are the file number for each individual data file

Reconstruction

Reconstructed by: Kenn Morales, Dan Schneberk, Travis White

Date: 02/ 24 – 25 /2010

Location: LLNL

Computer: Dell Precision 690

Reconstruction Software

Software: IMGREC

Version: 2.8.1.1c11

Script Files

LLNL_100_AND_160_Al_2slit-PDA_100225.txt
LLNL_100Al_2Slit-PDA_100223.txt
LLNL_160Al_2Slit-PDA_100223.txt
LLNL_160Al_1slit-PDA_100224.txt
LLNL_160AlCu_1slit-PDA_100224.txt
LLNL_160AlCu_2Slit-PDA_100223.txt
LLNL_300Cu_2Slit-PDA_100223.txt

Reconstructed Specimen Files(s)

Root Data Path: /Working /TP35_Industrial_CT_of_HME/LLNL/None/HEAFCAT/None/PDA_100223 /{sub directory}/

Slits	kVp	Filter	{sub directory}	Reconstruction file name
2	100	Al	/PDA_100Al	recobj_*nn*[1].sdt
2	160	Al	/PDA_160Al	recobj_*nn*.sdt
2	160	AlCu	/PDA_160AlCu	recobj_*nn*.sdt
2	300	Cu	/PDA_300Cu	recobj_*nn*.sdt
1	160	Al	/PDA_160Al1slit	recry_*nn*.sdt, ry_*nn*.sdt
1	160	AlCu	/PDA_160AlCu1slit	recry_*nn*.sdt, ry_*nn*.sdt

Observations:

[1] *nn* - are the file number for each individual data file

REFERENCES

1. "Standard Operating Procedure — Industrial Computed Tomography System Data Collection of Home-Made Explosives," U.S. Department of Homeland Security Science and Technology Directorate, DHS/STD/TSL-xx-xx, July 9, 2009.
2. Jerel A. Smith, Daniel J. Schneberk, Jeffrey S. Kallman, Harry E. Martz, Jr., David Hoey, *Documentation of the LLNL and Tyndall Micro-Computed-Tomography Systems*, Version 091216, Lawrence Livermore National Laboratory, LLNL-TR-421377, December 17, 2009.
3. Harry E. Martz, Jr., and Carl Crawford, *Validation of Explosive Simulants Requirement Specification*, Version 12, Lawrence Livermore National Laboratory, LLNL-TR-416983-REV 1, October 26, 2009.
4. Maurice B. Aufderheide and W. Travis White III, *HADES Calculations of the X-ray Linear Absorption Coefficient and Effective Atomic Number in Selected Materials*, Lawrence Livermore National Laboratory, LLNL-TR-xxxx-DRAFT, February 12, 2010.