

Summary Statistics for Fun Dough Data Acquired at LLNL

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Executive Summary

Measured Density: 1.2g/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)	2075	1830	1288	1121
	Standard Deviation (% of Mean)	3%	4%	4%	5%
	Entropy	5.52	5.58	5.41	5.54
	Modeled LAC (LMHU _D)	(na)	(na)	(na)	(na)
	Difference Between Model & Mean	(na)	(na)	(na)	(na)
Z _{eff}	From the mean measured LAC	8.6			
	From the modeled LAC	(na)			

Table 1. First-order statistics of the x-ray linear attenuation coefficient (LAC) in Fun 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 Play Dough™-like product, Fun Dough™, designated as PD. [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 2100 LMHU_D¹ at 100kVp to a low of about 1100 LMHU_D at 300kVp. The standard deviation of each measurement is around 1% of the mean. The entropy covers the range from 3.9 to 4.6. 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 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 8.5.

LLNL prepared about 50mL of the Fun Dough™ in a polypropylene vial and firmly compressed it immediately prior to the x-ray measurements. Still, layers can plainly be seen in the reconstructed images, indicating that the bulk density of the material in the container is affected by voids and bubbles. 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 PD (Fun Dough) X-ray Statistics**Report Date:** 3/11/2010**Author:** W. Travis White, III
*Typed or Printed Name*LLNL
*Organization***QA:** Robert D. Huber
*Typed or Printed Name*LLNL
*Organization***Material ID(s):** Fun Dough™

Source		Collimator	Sample Preparation	X-ray Measurement	Linear Attenuation Coefficient (LAC)			
Bias (kV)	Filters		Number of slits	Date	Date	Statistic	1 st order	2 nd order
	Material Thickness							
100	Al	1.943 mm	2	02/18/2010	02/18/2010	Mean	2075	48
						Std. Dev.	62	37
	Entropy Calculated	5.52				4.85		
		(na)				(na)		
160	Al	1.943 mm	2	02/18/2010	02/18/2010	Mean	1830	52
						Std. Dev.	64	40
	Entropy Calculated	5.58				4.94		
		(na)				(na)		
160	Al	1.943 mm	2	02/18/2010	02/18/2010	Mean	1288	48
						Std. Dev.	54	37
	Entropy Calculated	5.41				4.86		
		(na)				(na)		
Cu	1.905 mm	2	02/18/2010	02/18/2010	Mean	1121	56	
	Cu				2.972 mm	Std. Dev.	61	43
Entropy Calculated						5.54	5.01	
						(na)	(na)	
Z_{eff}	Z_{eff} based on measured LAC					8.57		
	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
	<i>Date</i>	<i>Name of Sender</i>

SUPPLEMENTAL ANALYSIS

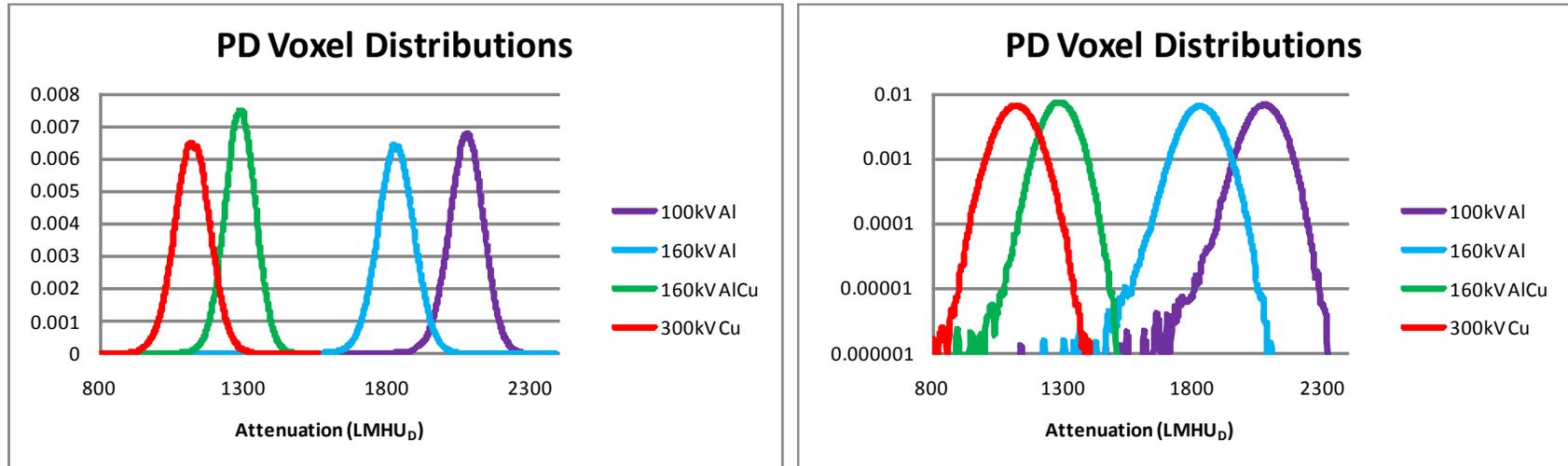


Figure 1. KDE histograms of values of the linear attenuation coefficient (LAC) for Fun Dough™ for four x-ray source settings (linear plots – left; semi-log plots – right).

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

Reference Specimens

	<i>graphite</i>	<i>ethanol</i>	<i>Delrin</i>	<i>water</i>	<i>Teflon</i>	<i>aluminum</i>
<i>100kV (Al) Mean</i>	1830	1082	1904	1486	3201	7543
<i>100kV (Al) Std Dev</i>	88	58	86	58	99	136
<i>160kV (AlCu) Mean</i>	1461	843	1400	1046	1998	3095
<i>160kV (AlCu) Std Dev</i>	60	45	55	46	58	72

Table 3. Linear attenuation coefficients (LMHU_D) of six reference materials as measured simultaneously with Fun Dough.

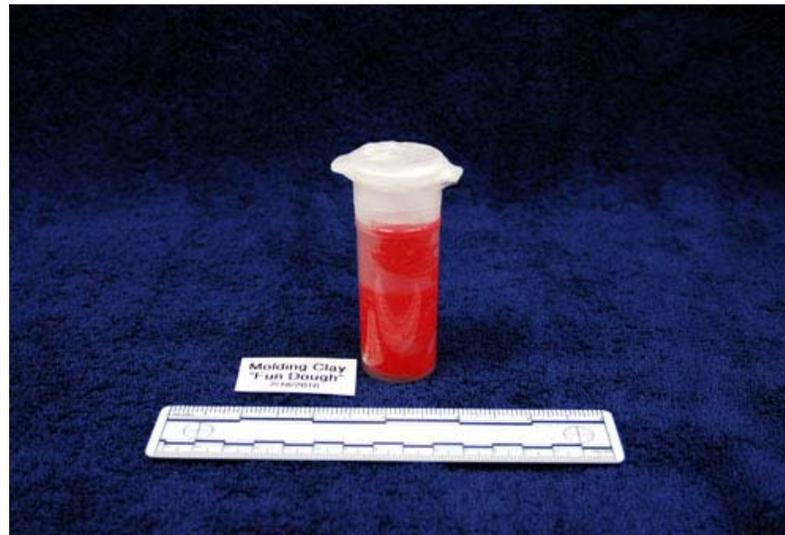
	100kV, Al 2 Slits	160kV, Al 2 Slits	160kV, AlCu 2 Slits	300kV, Cu 2 Slits	160kV, Al 1 Slit	160kV, AlCu 1 Slit
Image						
Segmented						
Eroded						
Gradient						

Figure 2. X-ray slice images with $150\mu\text{m} \times 150\mu\text{m} \times 150\mu\text{m}$ 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): _____

Specimen Preparation

1. **Person responsible:** Rich Whipple
2. **Date/time:** 02/18/2010
3. **Location:** LLNL
4. **Identifier:** Fun Dough™, marketed by Rose Art Industries, Inc., Livingston, NJ 07039
5. **Preparation procedure:** Off-the-shelf commercial product
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 = 1.20 g/cc
8. **Image of Sample:**



9. **Observations:** _____

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 .set 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/PD_100218 /{sub directory}/Raw_Data

Specimen ID	Date	Radiographer	Slits	kVp	mA	Al Filter (mm)	Cu Filter (mm)	Integration <i>dpix</i> Setting [time/frame (s)]	{sub directory}	File Name
PD	100218	Morales	2	100	1.1	1.943	0	10 [3.2s]	/PD_100Al	PD_100Al _{nn} .sdt ¹
	100218	Morales	2	160	0.7	1.943	0	5 [2.3s]	/PD_160Al	PD_160Al _{nn} .sdt
	100218	Morales	2	160	4.35	1.943	1.905	8 [2.8s]	/PD_160AlCu	PD_160AlCu _{nn} .sdt
	100218	Morales	2	300	2.3	0	2.972	4 [2.1s]	/PD_300Cu	PD_300Cu _{nn} .sdt
	100218	Morales	1	160	0.7	1.943	0	5 [2.3s]	/PD_160Al 1slit	PD_160Al 1slit _{nn} .sdt
	100218	Morales	1	160	4.35	1.943	1.905	8 [2.8s]	/PD_160AlCu 1slit	PD_160AlCu 1slit _{nn} .sdt

Dark current, mid-range, bright field and I_0

Root Data Path: /Working /TP35_Industrial_CT_of_HME/LLNL/None/HEAFCAT/None/PD_100218 /{sub directory}/Raw_Data

Slits	kVp	Filter	{sub directory}	Dark Image File Name	Mid-Brightness Image File Name	Max Brightness Image File Name	I_0 Image File Name
2	100	Al	/PD_100Al	PD_100Al _{drk} .sdt	PD_100Al _{mid} .sdt	PD_100Al _{lit} .sdt	PD_100Al _{bak} .sdt
2	160	Al	/PD_160Al	PD_160Al _{drk} .sdt	PD_160Al _{mid} .sdt	PD_160Al _{lit} .sdt	PD_160Al _{bak} .sdt
2	160	AlCu	/PD_160AlCu	PD_160AlCu _{drk} .sdt	PD_160AlCu _{mid} .sdt	PD_160AlCu _{lit} .sdt	PD_160AlCu _{bak} .sdt
2	300	Cu	/PD_300Cu	PD_300Cu _{drk} .sdt	PD_300Cu _{mid} .sdt	PD_300Cu _{lit} .sdt	PD_300Cu _{bak} .sdt
1	160	Al	/PD_160Al 1slit	PD_160Al 1slit _{drk} .sdt	PD_160Al 1slit _{mid} .sdt	PD_160Al 1slit _{lit} .sdt	PD_160Al 1slit _{bak} .sdt
1	160	AlCu	/PD_160AlCu 1slit	PD_160AlCu 1slit _{drk} .sdt	PD_160AlCu 1slit _{mid} .sdt	PD_160AlCu 1slit _{lit} .sdt	PD_160AlCu 1slit _{bak} .sdt

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

Reconstruction

Reconstructed by: Travis White

Date: 02/23/2010

Location: LLNL

Computer: Dell Precision 670 and Dell Precision 690

Reconstruction Software

Software: IMGREC

Version: 2.8.1.1c11

Script Files

LLNL_100Al_2slit-PD_100223.txt

LLNL_160Al_2slit-PD_100223.txt

LLNL_160AlCu_2Slit-PD_100222.txt

LLNL_300Cu_2Slit-PD_100222.txt

LLNL_160Al_1slit-PD_100222.txt

LLNL_160AlCu_1slit-PD_100222.txt

Reconstructed Specimen Files(s)

Root Data Path: /Working /TP35_Industrial_CT_of_HME/LLNL/None/HEAFCAT/None/PD_100218 /{sub directory}/

Slits	kVp	Filter	{sub directory}	Reconstruction file name
2	100	Al	/PD_100Al	recobj_ <i>nn</i> ¹ .sdt
2	160	Al	/PD_160Al	recobj_ <i>nn</i> .sdt
2	160	AlCu	/PD_160AlCu	recobj_ <i>nn</i> .sdt
2	300	Cu	/PD_300Cu	recobj_ <i>nn</i> .sdt
1	160	Al	/PD_160Al1slit	recry_ <i>nn</i> .sdt ,ry_ <i>nn</i> .sdt
1	160	AlCu	/PD_160AlCu1slit	recry_ <i>nn</i> .sdt ,ry_ <i>nn</i> .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.