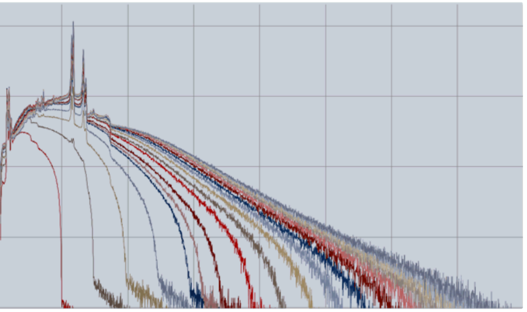
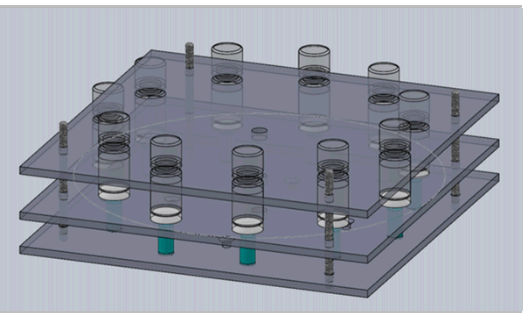
SAND2014-4894C

Qualitative Comparison of Experimental and Simulated Cone Beam Computed Tomography Data





Kyle Thompson
Sandia National Laboratories
Structural Dynamics and X-ray/NDE
krthomp@sandia.gov
505-844-0347

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Edward Jimenez[1]

Laurel Orr[1]

Ismael Perez[1]

Burke Kernen[2]

Madia Stein

Sandia National Laboratories

1 *Software Systems R&D Department*

2 *Structural Dynamics, X-ray, and Non-Destructive Evaluation Department*

Outline

- Motivation
- Cone Beam Computed Tomography Fundamentals
- Measurement of the effective X-ray Attenuation Coefficients
- Computed Tomography Voxel Values
- Comparison of Experimental Data
- Conclusion

Motivation – What & Why

- Want knowledge of what the voxel values from various cone beam industrial/research CT systems represent and how they can be interpreted
- How do these CT values compare to measured x-ray attenuation values?
- What factors affect the CT voxel values?
- Want to know if various materials can be identified from their CT values
- Eventually would like to compare values from different CT systems to see if quantitative data can be obtained and what is the expected variation

Cone Beam Computed Tomography

- Acquire multiple digital radiographic (DR) images as part is rotated 360 degrees
- Correct images for fixed pattern noise create attenuation images (i.e. image of the transmitted x-ray radiation)
- Calculate negative log of attenuation image
- Reconstruct a three dimensional map of the effective x-ray attenuation coefficients (Filter and Backproject)

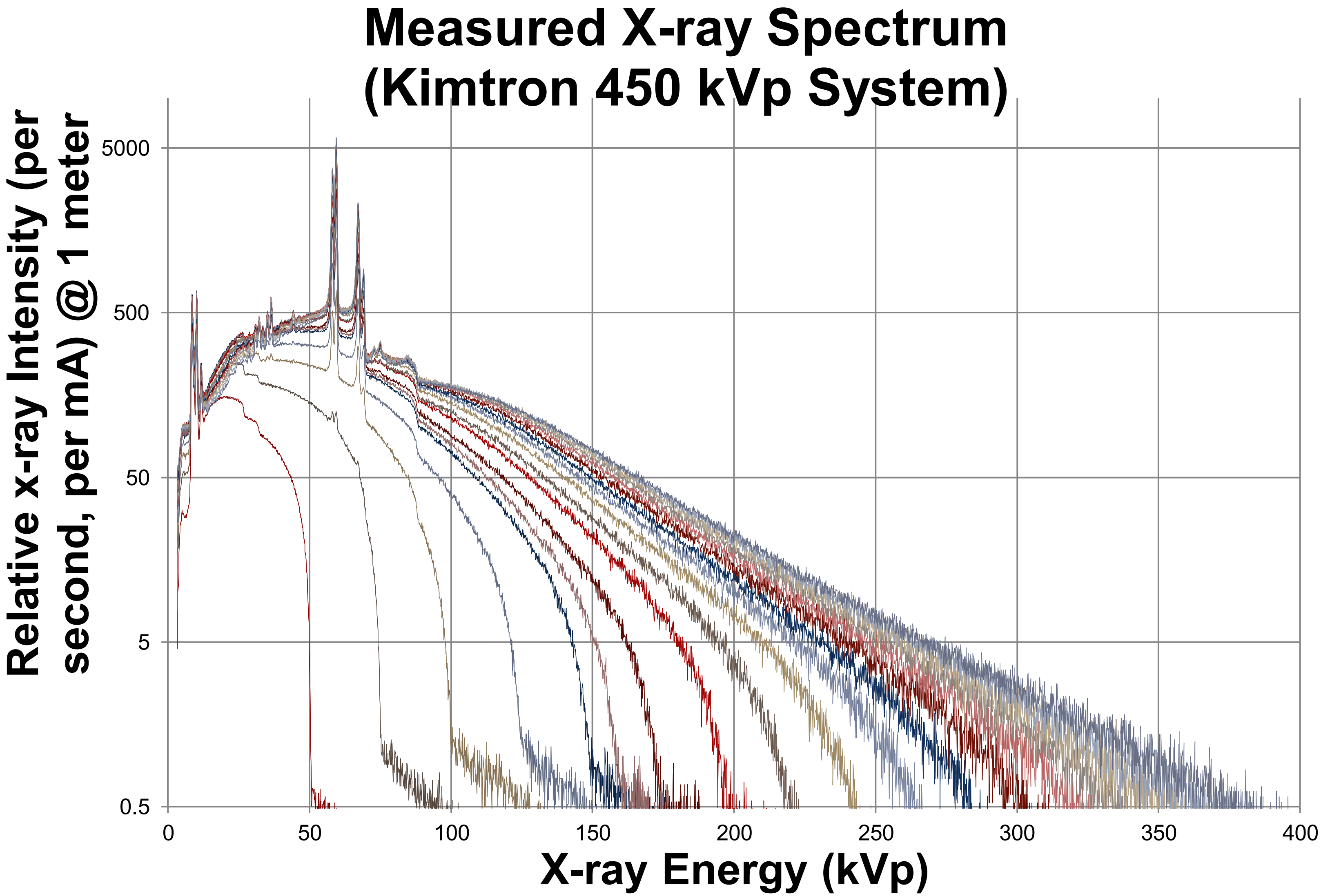
Acquire DR Images

Create Corrected Attenuation Images

Calculate Negative Log Images

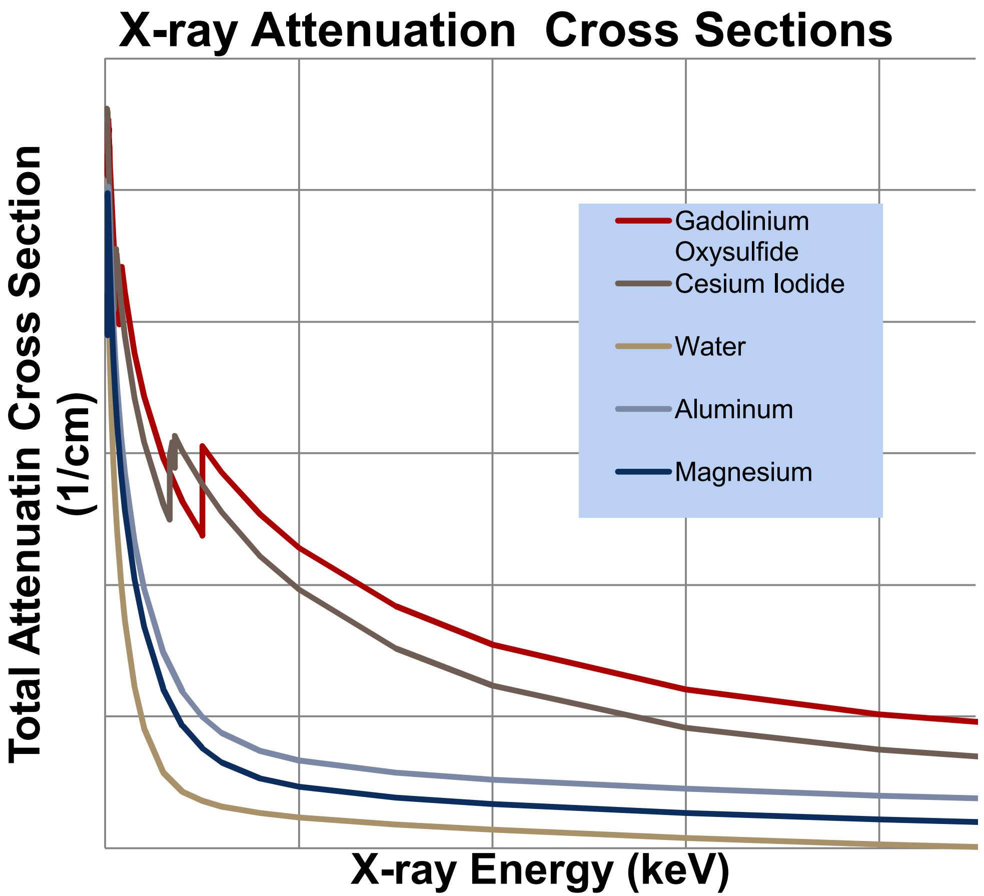
Filter & Backproject Projection Images into 3D Voxels

X-ray Beam - Bremsstrahlung



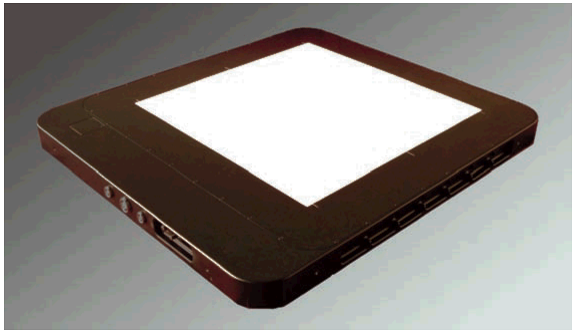
X-ray Attenuation

- Energy Dependent
- Dependent on CT/DR detector response
- Bremsstrahlung CT/DR systems will measure an Effective Attenuation coefficient
  - Integrated over X-ray spectrum
  - Function of Detector Response



X-Ray CT Setup

- Kimtron 450 kV x-ray system w/ Comet MXR 451 HP/11 tube
- Perkin Elmer XRD 1621 detector
- 999 projections
- X-ray Energies 100, 200, 300, 400 kVp
- Data Reconstructed with three different sets of software
  - Two commercial software packages
  - One internally developed software package

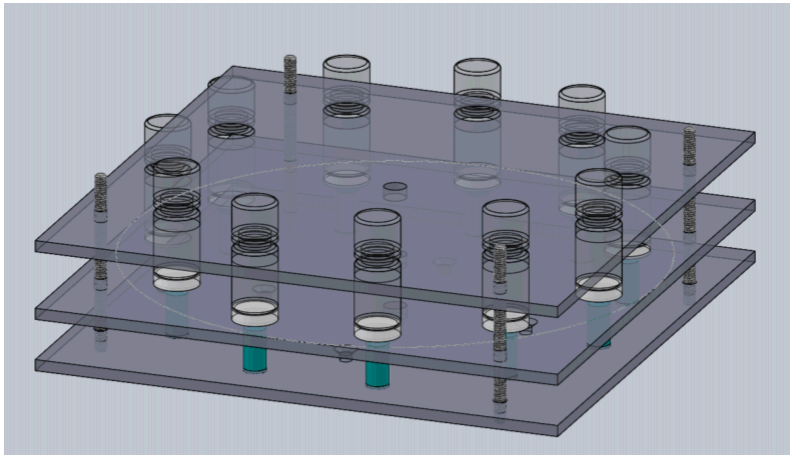


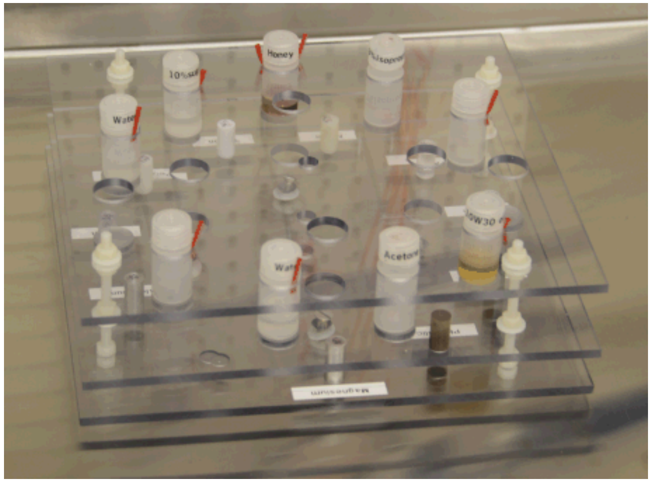
CT Reconstruction Settings

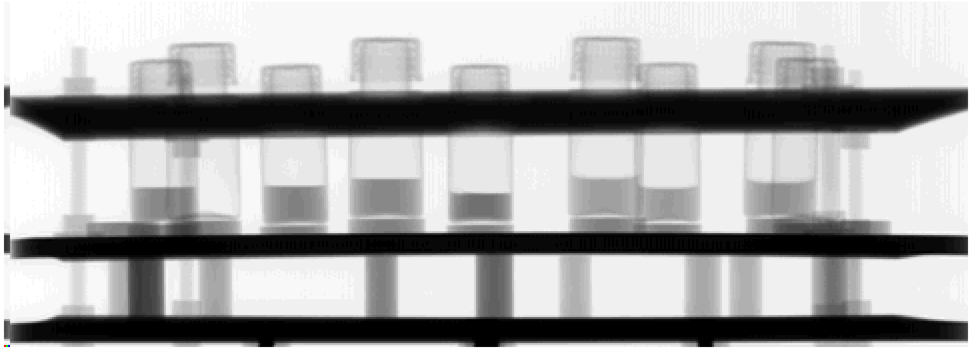
- Two software packages output floating point reconstruction values with a value of zero for air
- One software package outputs 16-bit integer values (floating point not available)
- Multiple x-ray beam hardening correction values were used on one software package
- GPU implementation Feldkamp reconstruction algorithm

Experimental Equipment

- Sample holders designed and fabricated
- 15 mL polypropylene containers
- Reference parts on bottom of sample holder (Aluminum, Magnesium, & plastics)

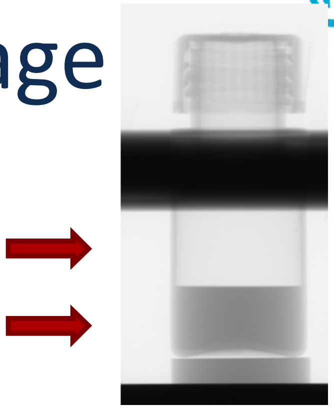


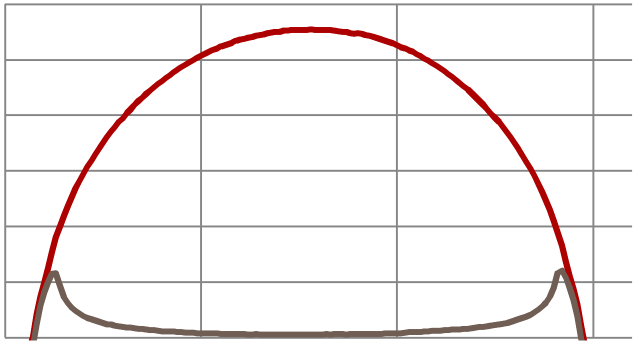


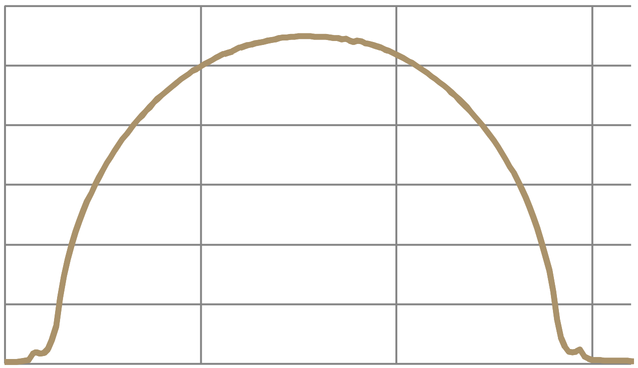


X-ray Attenuation from a DR Image

- Select digital radiograph image (negative log image) with isolated sample
- Extract line profiles from digital radiograph
  - Sample w/ container
  - Container
- Subtract container line profile from sample w/ container to obtain sample line profile

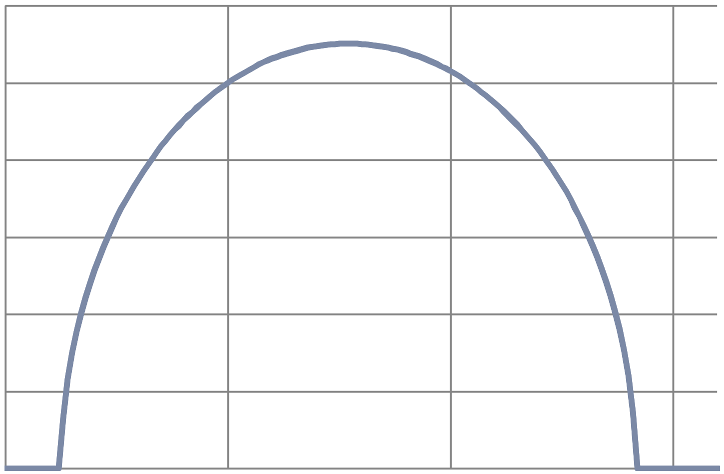




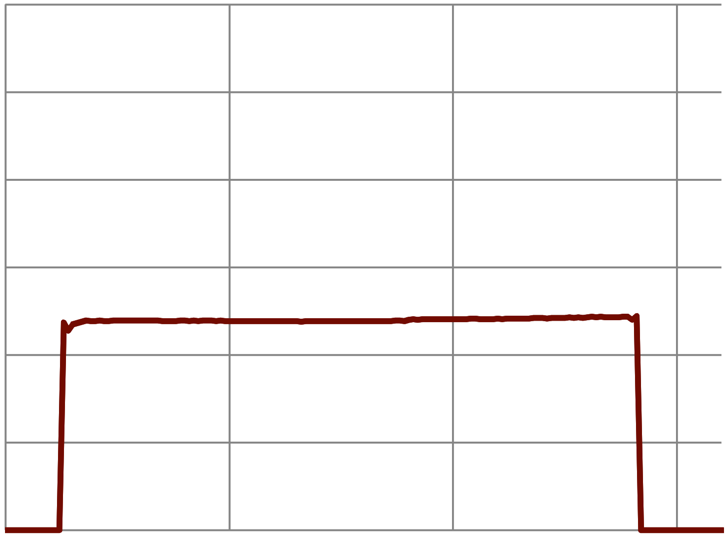


X-ray Attenuation from a DR Image

- Calculate sample thickness profile

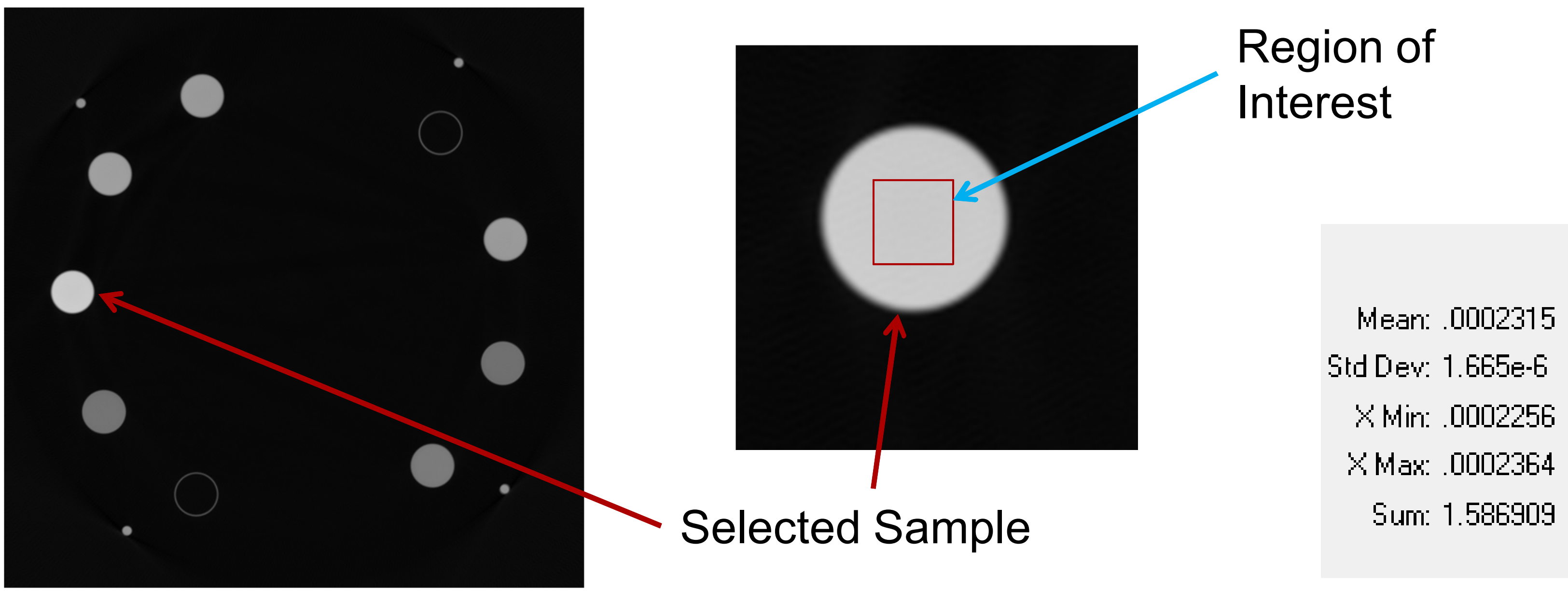


- Divide sample line profile by sample thickness



X-ray Attenuation from a CT Image

- Select CT image(s) with sample of interest
- Calculate the mean voxel value from a region of interest within the sample



CT Voxel Value Scaling

- CT voxel values come in many forms
  - 8-32 bit integer
  - 32 bit floating point
    - Rescaled to 8-16 bit integer
- Medical systems use Hounsfield Units
  - Two point linear scaling system
    - Air = -1000
    - Water = 0
    - $HU = 1000 * \left(\frac{CT\ Value - Water\ CT\ value}{Water\ CT\ value}\right)$
    - If air Value is not 0, must subtract air value from all values
- If industrial CT voxel values are not floating point (air=0), then subtract air value

Factors Affecting CT Voxel Values

- X-ray Beam Energy
- Data calibration
- Data Format
- Data Pre-processing/scaling
  - Beam Hardening Corrections
  - Data Bit depth
- X-ray Detector Response
- CT Reconstruction Software/Algorithms
- Noise
- Scatter
- Sampling frequency

CT Voxel Values

Software1	X-ray Energy			
	100	200	300	400
Water	0.023736	0.020038	0.018736	0.018098
Acetone	0.016992	0.0148	0.013988	0.013619
Oil	0.016992	0.0148	0.013988	0.013619
Alcohol	0.017564	0.015603	0.014426	0.014043
Honey	0.031454	0.027068	0.025416	0.024551
Magnesium	0.067101	0.049481	0.044041	0.041362
Aluminum	0.096662	0.072736	0.065097	0.061446

Software2	X-ray Energy			
	100	200	300	400
Water	0.000175	0.000148	0.000138	0.000134
Acetone	0.000125	0.000109	0.000103	0.000101
Oil	0.000138	0.000122	0.000115	0.000112
Alcohol	0.000129	0.000113	0.000107	0.000104
Honey	0.000232	0.0002	0.000188	0.000181
Magnesium	0.000494	0.000366	0.000326	0.000306
Aluminum	0.000712	0.000537	0.000483	0.000455

Software1/Software2	X-ray Energy			
	100	200	300	400
Water	136.0212	135.3899	135.4743	135.4641
Acetone	136.2622	135.2834	135.5417	135.5095
Oil	136.1964	139.0074	135.5551	135.5766
Alcohol	136.2591	138.3245	135.4573	135.5463
Honey	135.8691	135.5408	135.5509	135.6387
Magnesium	135.7485	135.2687	135.0524	135.2593
Aluminum	135.8571	135.4985	134.7485	135.047
	Averge	135.7839		

CT Voxel Values - cont

	Software1	Software2 (16 bit)	Software 2 (32 bit)	Software3
Water	0.0171	3291	3606	15122
10W30 Oil	0.0149	2865	3134	15050
Lotion	0.0168	3194	3493	15105
Sugar Water	0.0184	3533	3870	15160
Honey	0.0233	4446	4882	15315
Mg	0.0321	6183	6810	15617
Al	0.0484	9332	10284	16117
Lexan	0.0183	3536	3888	15162
Polyethylene	0.0220	4239	4662	15281
Teflon	0.0311	6008	6613	15578
Nylon	0.0182	3501	3841	15160
Acrylic	0.0184	3554	3897	15168
Delrin	0.0153	2957	3229	15065
Nylatron	0.0203	3923	4313	15229
Phenolic	0.0208	4014	4415	15245
Air	0.0000	16	22	14564

	Software1	Software2 (16 bit Int)	Software2 (32 bit Int)	Software 3
Water	1.00	1.00	1.00	1.00
10W30 Oil	0.87	0.87	0.87	0.87
Lotion	0.98	0.97	0.97	0.97
Sugar Water	1.08	1.07	1.07	1.07
Honey	1.36	1.35	1.36	1.35
Mg	1.87	1.88	1.89	1.89
Al	2.82	2.84	2.86	2.78
Lexan	1.07	1.07	1.08	1.07
Polyethylene	1.28	1.29	1.29	1.28
Teflon	1.82	1.83	1.84	1.82
Nylon	1.06	1.06	1.07	1.07
Acrylic	1.08	1.08	1.08	1.08
Delrin	0.89	0.90	0.89	0.90
Nylatron	1.19	1.19	1.20	1.19
Phenolic	1.21	1.22	1.23	1.22
Air	0.00	0.00	0.00	0.00

CT Voxel Values

Software1	X-ray Energy			
	100	200	300	400
Water	0.023736	0.020038	0.018736	0.018098
Acetone	0.016992	0.0148	0.013988	0.013619
Oil	0.016992	0.0148	0.013988	0.013619
Alcohol	0.017564	0.015603	0.014426	0.014043
Honey	0.031454	0.027068	0.025416	0.024551
Magnesium	0.067101	0.049481	0.044041	0.041362
Aluminum	0.096662	0.072736	0.065097	0.061446

Direct				
	100	200	300	400
Water	0.239656	0.201497	0.188008	0.182033
Acetone	0.170706	0.148811	0.140485	0.136852
Oil				
Alcohol				
Honey	0.324977	0.272673	0.25766	0.24992
Magnesium				
Aluminum				

Direct/Software1	X-ray Energy			
	100	200	300	400
Water	10.09685	10.05588	10.03455	10.0582
Acetone	10.04634	10.05477	10.04334	10.04883
Oil	0	0	0	0
Alcohol	0	0	0	0
Honey	10.33193	10.07381	10.13781	10.17979
Magnesium	0	0	0	0
Aluminum	0	0	0	0

CT Voxel and Simulated Values

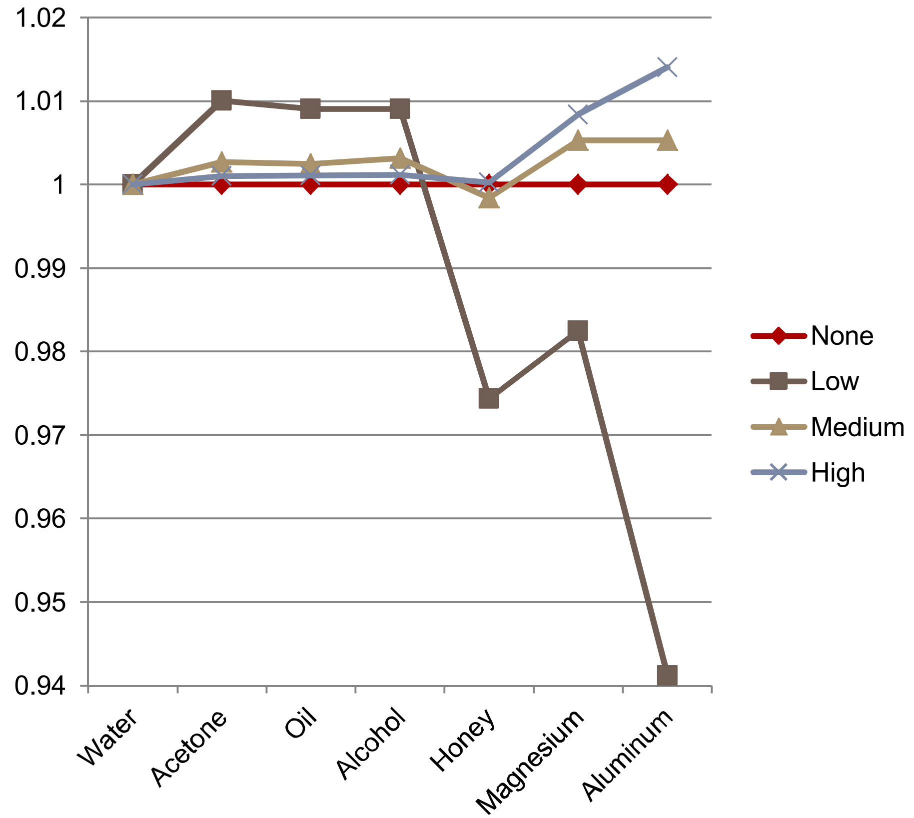
Software1		X-ray Energy		
	100	200	300	400
Water	0.023736	0.020038	0.018736	0.018098
Acetone	0.016992	0.0148	0.013988	0.013619
Oil	0.016992	0.0148	0.013988	0.013619
Alcohol	0.017564	0.015603	0.014426	0.014043
Honey	0.031454	0.027068	0.025416	0.024551
Magnesium	0.067101	0.049481	0.044041	0.041362
Aluminum	0.096662	0.072736	0.065097	0.061446

Simulated				
	100	200	300	400
Water	0.239656	0.201497	0.188008	0.182033
Acetone	0.170706	0.148811	0.140485	0.136852
Oil				
Alcohol				
Honey	0.324977	0.272673	0.25766	0.24992
Magnesium				
Aluminum				

Simulated/Software1		X-ray Energy		
	100	200	300	400
Water	10.09685	10.05588	10.03455	10.0582
Acetone	10.04634	10.05477	10.04334	10.04883
Oil	0	0	0	0
Alcohol	0	0	0	0
Honey	10.33193	10.07381	10.13781	10.17979
Magnesium	0	0	0	0
Aluminum	0	0	0	0

Effect of Beam Hardening Correction on CT Voxel Values

Software2		100 kVp X-ray Energy Beam Hardening Correction		
	None	Low	Medium	High
Water	0.000175	6.51E-03	3.78E-03	0.002563
Acetone	0.000125	0.004697	0.002711	0.001833
Oil	0.000138	0.005193	0.002999	0.002029
Alcohol	0.000129	0.00485	0.002804	0.001895
Honey	0.000232	0.008412	0.005011	0.003401
Magnesium	0.000494	0.018109	0.010774	0.007321
Aluminum	0.000712	0.024972	0.015509	0.010597



Conclusions

- CT voxel values obtained from several image reconstruction software packages are equivalent to a directly measured attenuation coefficient
- Scaling will vary for each software package
- Different data types have to be interpreted using different methods
- Reference materials are essential for data scaling
- Preliminary results indicate Beam hardening corrections provide a multiplicative shift in the CT voxel values

Future Work

- Continue to analyze data (> 8 TB of data acquired)
- Compare CT number from different detectors/systems
- Investigate detection thresholds, contrast sensitivity
- Compare simulated cone beam CT data to experimental data

Questions?

Kyle Thompson
krthomp@sandia.gov
505-844-0347