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"Materials and methods employed to validate a CT scanner's approximation of effective atomic number"

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Directorate of Healthcare Science & Technology

Plymouth Hospitals NHS Trust

Dual Energy imaging

Photoelectric effect + Compton scattering = X-ray attenuation

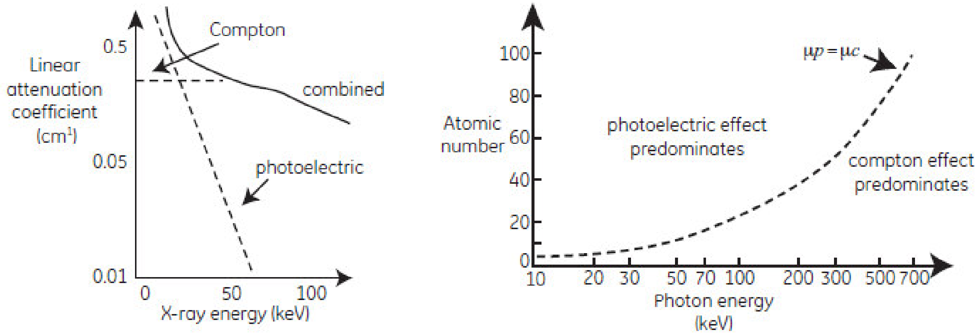
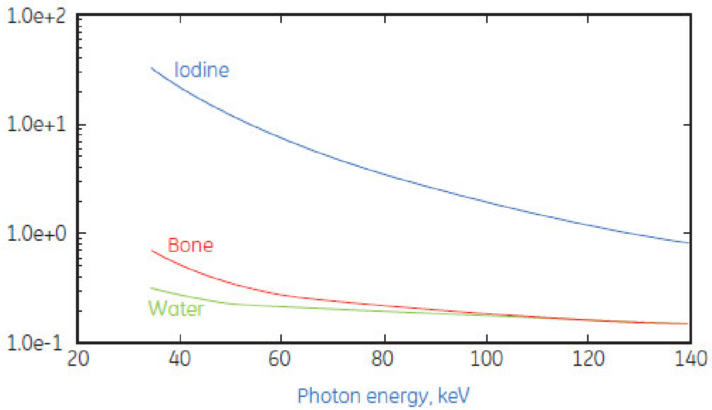


Figure 2: Two primary mechanisms for X-ray attenuation

X-ray mass attenuation coefficients



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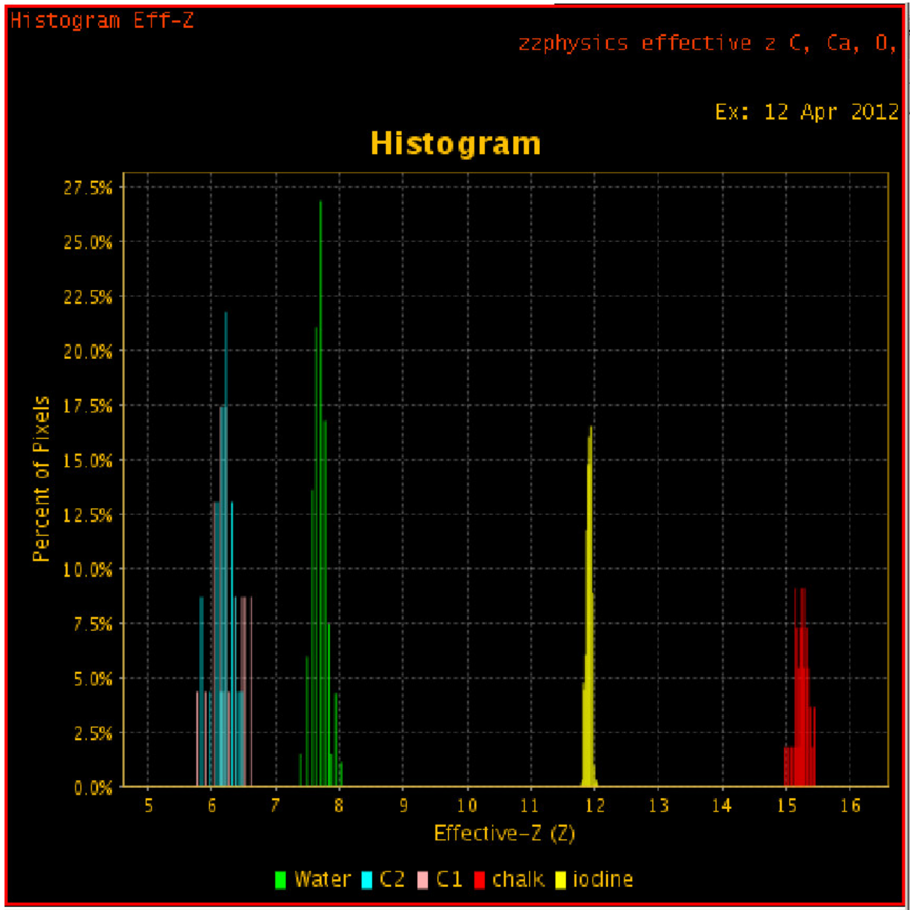
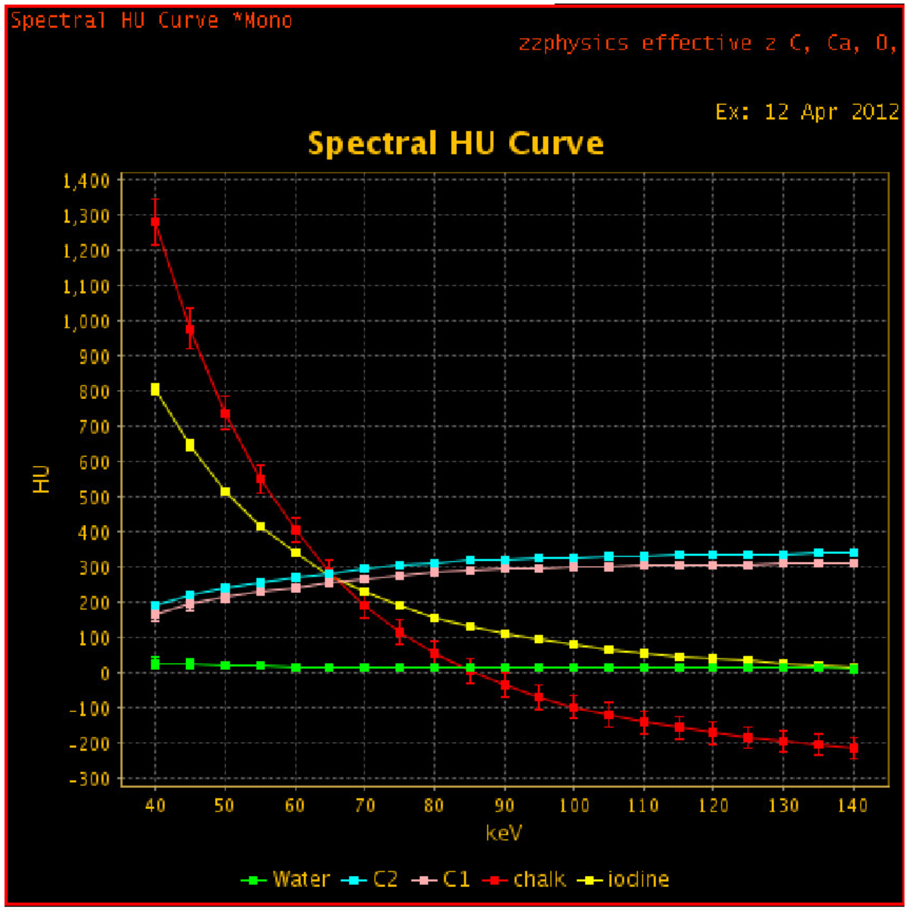
The Claims….

- I/H2O/Ca/Other quantification
- Virtual non contrast imaging
- KeV data sets (contrast optimisation)
- Beam hardening reduction
- ROI defined spectral Hounsfield unit curves
- Calcium subtraction
- **Measurement of effective atomic number (Z)**

The pictures





Percentage of pixels vs Effective Z

HU vs Energy

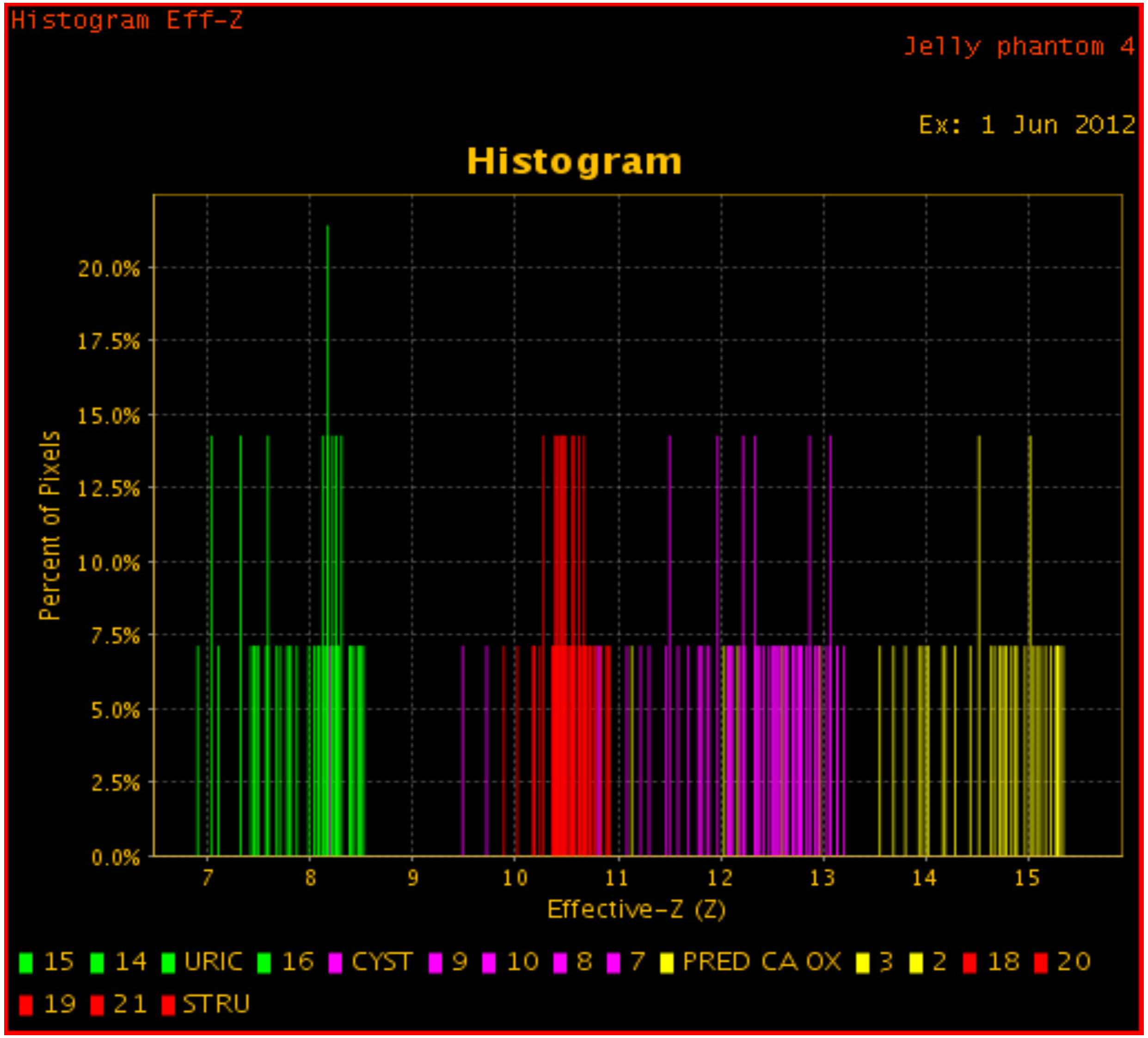
Gemstone Spectral Imaging

Conclusion

Because determining the chemical composition of renal calculi can help a urologist select a strategic course of action—sometimes even before the doctor meets the patient—Gemstone Spectral Imaging Viewer's Effective-Z Image Type and Histogram feature can be used to find the best available treatment based on stone composition. Through use of effective atomic numbers, GSI allows the physician to quantify kidney stone chemical composition and make use of these data in ways conventional CT cannot.

Medical Director, Radiologist
Atlantic Medical Imaging
Galloway, NJ

The use? – Local work



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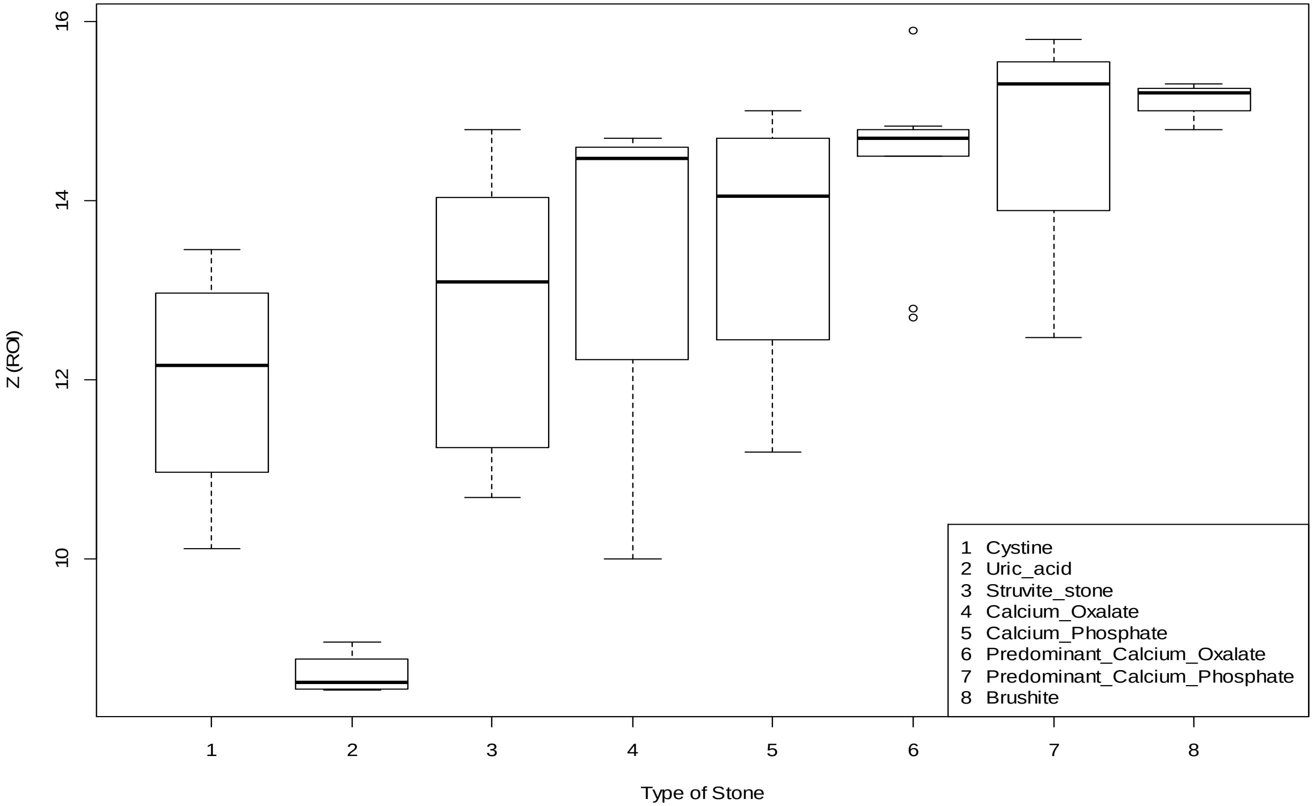
The use? – Local work



Local work

- Only Uric acid separation possible
- Effective Z appears to increase separation from HU at 80 and 140KV
- To bear in mind, the real difference in effective atomic number among the different non uric acid stone is small (especially for mixed stones), so can we accurately predict atomic number and their differences?
- Further large sample analysis needed.

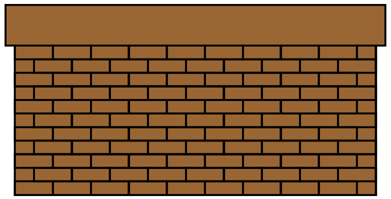
The validation

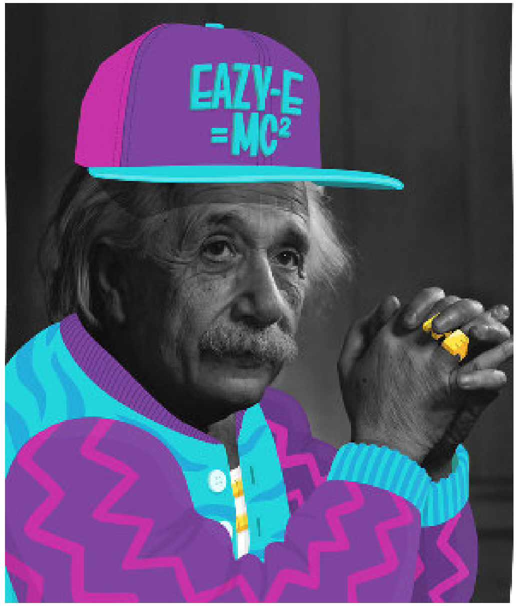
1. How does GSI measure/calculate ROI effective Z?
2. Scan known materials and get the scanner to tell us the effective atomic number!
3. Compare the difference

The Problem…

- Need to test over a suitable range of Z's
- Difficult to get hold of "pure" elements

Calling all Mad Chemists!





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Help from the Chemists!

Copper STD	3% $Cu(NO_3)_2$ 97% HNO_3
Zinc STD	3% $Zn(NO_3)_2$ 97% HNO_3
Lithium STD	3% $Li(NO_3)$ 97% HNO_3
Potassium dihydrogen orthophosphate	KH_2PO_4
Boric acid	H_3BO_4
EDTA	$C_{10}H_{14}N_2O_8Na_2$ $2H_2O$
Ammonium sulfate	$(NH_4)_2SO_4$
Potassium Permanganate	$KMnO_4$
Barium Sulphate	$BaSO_4$

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How does the Scanner calculate the effective atomic number?

"The effective atomic number is defined in terms of the attenuation "signature" for a material. That is, if the material that we scan behaves like a periodic element when an atomic number X, then we say that the effective atomic number of that material is X"

How does the Scanner calculate the effective atomic number?

- Scanner uses the ratio of total attenuation at 70KeV and 120KeV.
- It matches this identified ratio to a point on the curve of known elements of known atomic number.
- This is then used as a calibration curve to calculate the effective atomic number of unknown compounds, elements and mixtures.

Scanner tells us Z, use NIST to get the attenuation ratio of 70KeV/120KeV

NIST
National Institute of Standards and Technology
Physical Meas. Laboratory

XCOM

Element/Compound/Mixture Selection

In this database, it is possible to obtain photon cross section data for a single element, compound, or mixture (a combination of elements and compounds). Please fill out the following information:

Help

Identify material by:

- ○ Element
- ○ Compound
- ◉ Mixture

Method of entering additional energies: (optional)

- ◉ Enter additional energies by hand
- ○ Additional energies from file (*Note: Your browser must be file-upload compatible*)

Submit Information | Reset

XCOM

Example (for Iodine mixtures)

Enter the formulae and relative weights separated by a space for each compound. One compound per line. For example:

```
H2O 0.9
NaCl 0.1
```

Note: Weights not summing to 1 will be normalized.

```
C18H24I3N3O4 0.0741
H2O 0.9649
```

Optional output title: 10%

Graph options:

- [x] Total Attenuation with Coherent Scattering
- [ ] Total Attenuation without Coherent Scattering
- [ ] Coherent Scattering
- [ ] Incoherent Scattering
- [ ] Photoelectric Absorption
- [ ] Pair Production in Nuclear Field
- [ ] Pair Production in Electron Field

- [ ] None

Additional energies in MeV: (optional) (up to 75 allowed)

Note: Energies must be between 0.001 - 100000 MeV (1 keV - 100 GeV) (only **4** significant figures will be used). One energy per line. Blank lines will be ignored.

```
0.07
0.120
```

- [ ] **Include the standard grid**

Energy Range:

Minimum: 0.001 MeV

Maximum: 100000 MeV

Submit Information | Reset

Example (for Iodine mixtures)

Zoom in on energy range: (must be between 0.001 - 100000 MeV)

Note: If all data are not displayed in the graph, modify the energy range to view graphed data in the region of interest.
Energy range must cover at least one factor of ten (e.g., 100 to 1000 MeV).

Minimum: 0.001 MeV Maximum: 100000 MeV

Change Energy Range

Constituents (Atomic Number : Fraction by Weight)

```
Z=1    : 0.931054
Z=6    : 0.021206
Z=7    : 0.004122
Z=8    : 0.006277
Z=53   : 0.037342
```

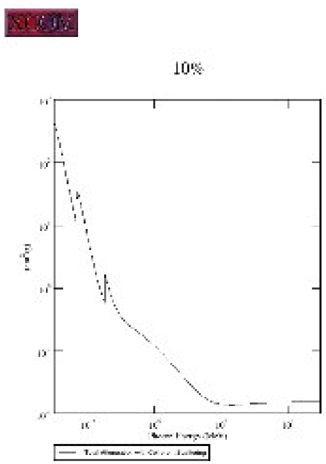
To download data in spreadsheet (array) form, choose a delimiter and use the checkboxes in the table heading. After downloading, save the output by using your browser's `Save As` feature.

Delimiter:

- ◉ space
- ○ | (vertical bar)
- ○ tab
- ○ newline

Download data Reset

Edge	(required) Photon Energy	Scattering		Photoelectric Absorption	Pair Production		Total Attenuation	
		Coherent	Incoherent		In Nuclear Field	In Electron Field	With Coherent Scattering	Without Coherent Scattering
	MeV	cm^2/g	cm^2/g	cm^2/g	cm^2/g	cm^2/g	cm^2/g	cm^2/g
	7.000E-02	8.230E-03	3.040E-01	1.758E-01	0.000E+00	0.000E+00	4.880E-01	4.798E-01
	1.200E-01	3.179E-03	2.705E-01	3.834E-02	0.000E+00	0.000E+00	3.120E-01	3.088E-01



Example (for Iodine mixtures)

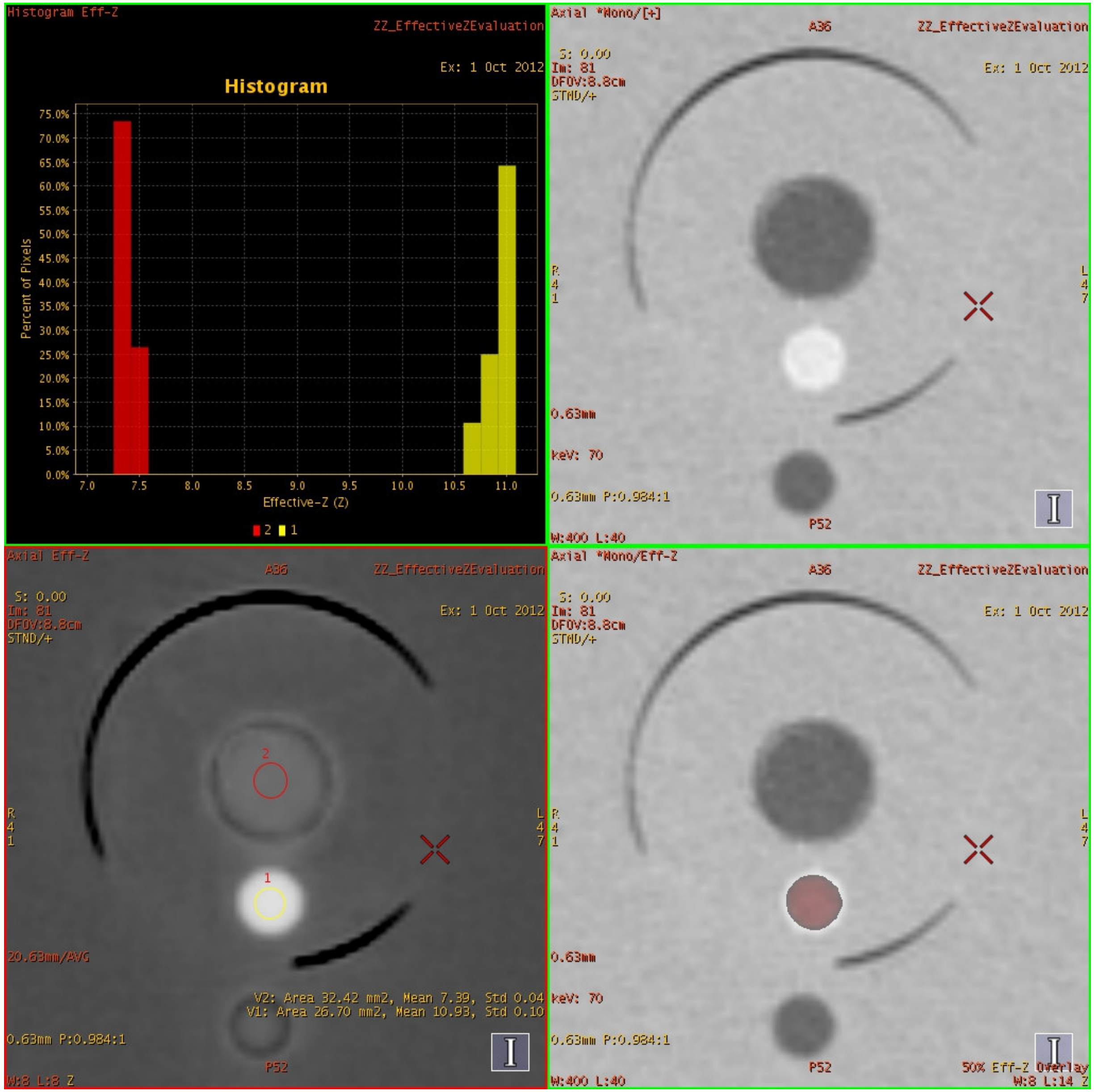
Download data Reset

Edge	(required) Photon Energy	Scattering		Photoelectric Absorption	Pair Production		Total Attenuation	
		Coherent	Incoherent		In Nuclear Field	In Electron Field	With Coherent Scattering	Without Coherent Scattering
	MeV	cm^2/g	cm^2/g	cm^2/g	cm^2/g	cm^2/g	cm^2/g	cm^2/g
	7.000E-02	8.230E-03	3.040E-01	1.758E-01	0.000E+00	0.000E+00	4.880E-01	4.798E-01
	1.200E-01	3.179E-03	2.705E-01	3.834E-02	0.000E+00	0.000E+00	3.120E-01	3.088E-01

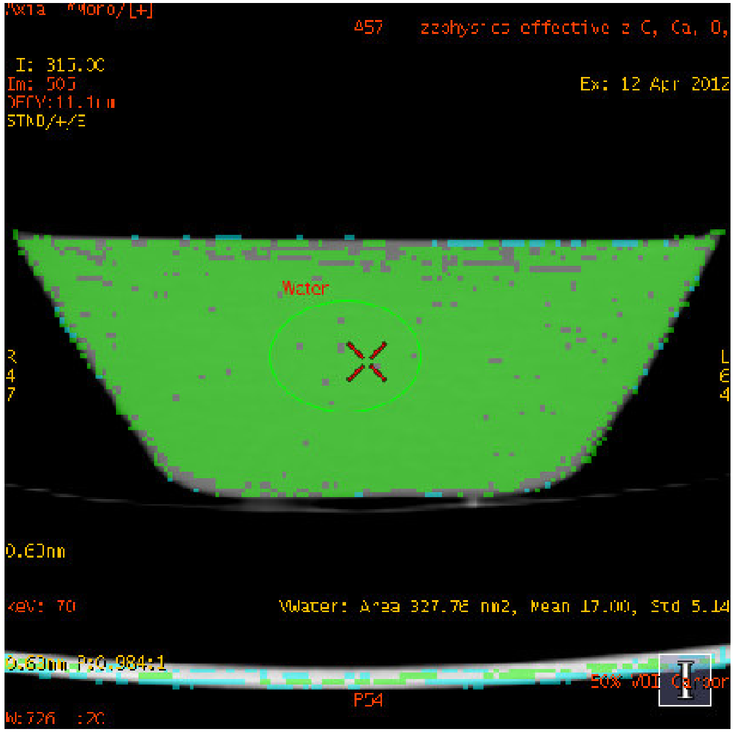
The materials

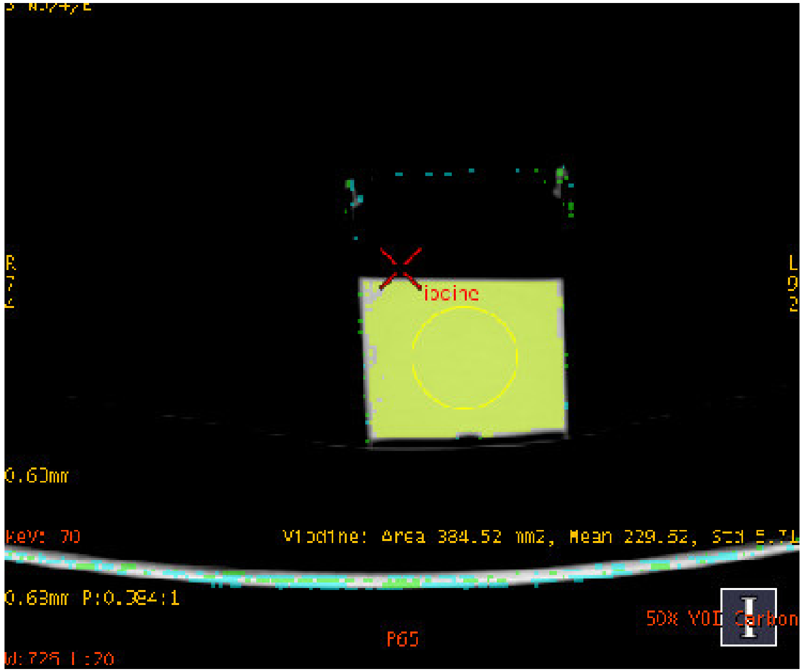
- Water
- Carbon (graphite)
- Air
- Aluminium
- Chalk
- Iodine concentrations
- Our Chemistry set ☺

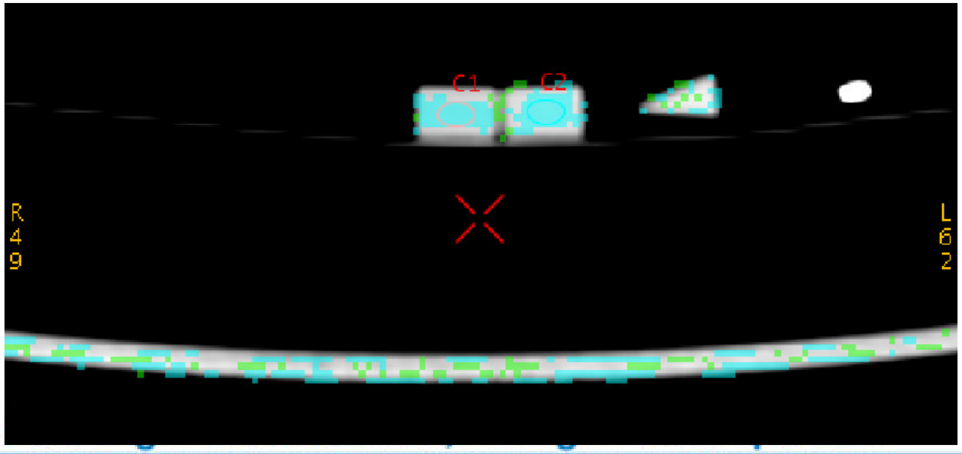
Iodine concentration in 16cm Perspex phantom

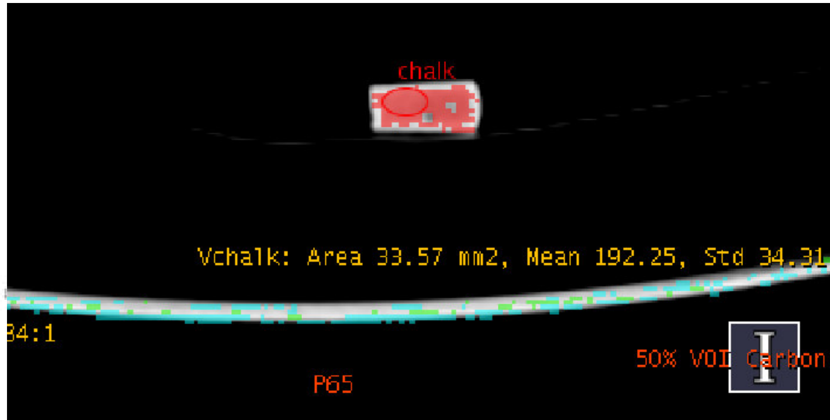


Elements and mixtures



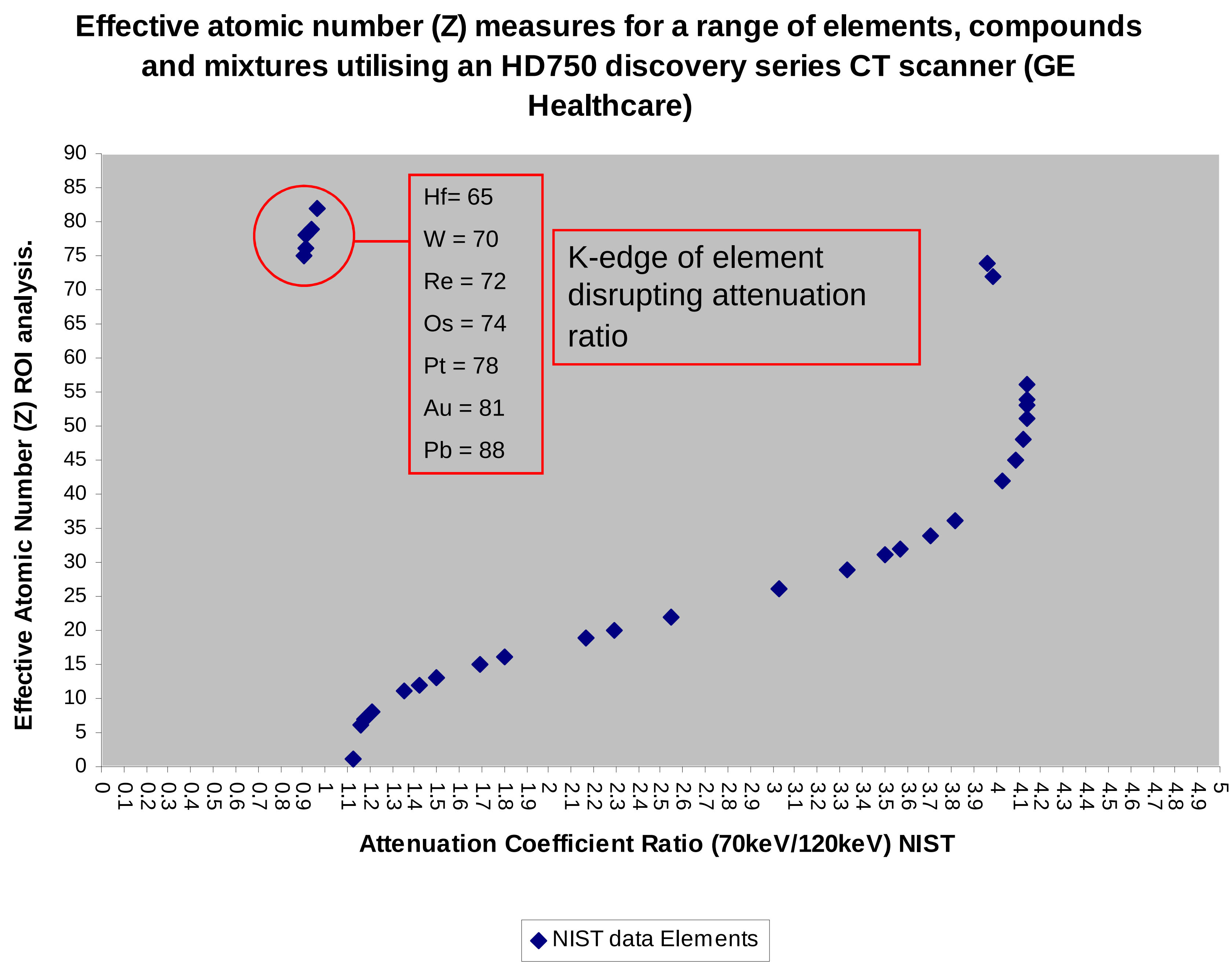




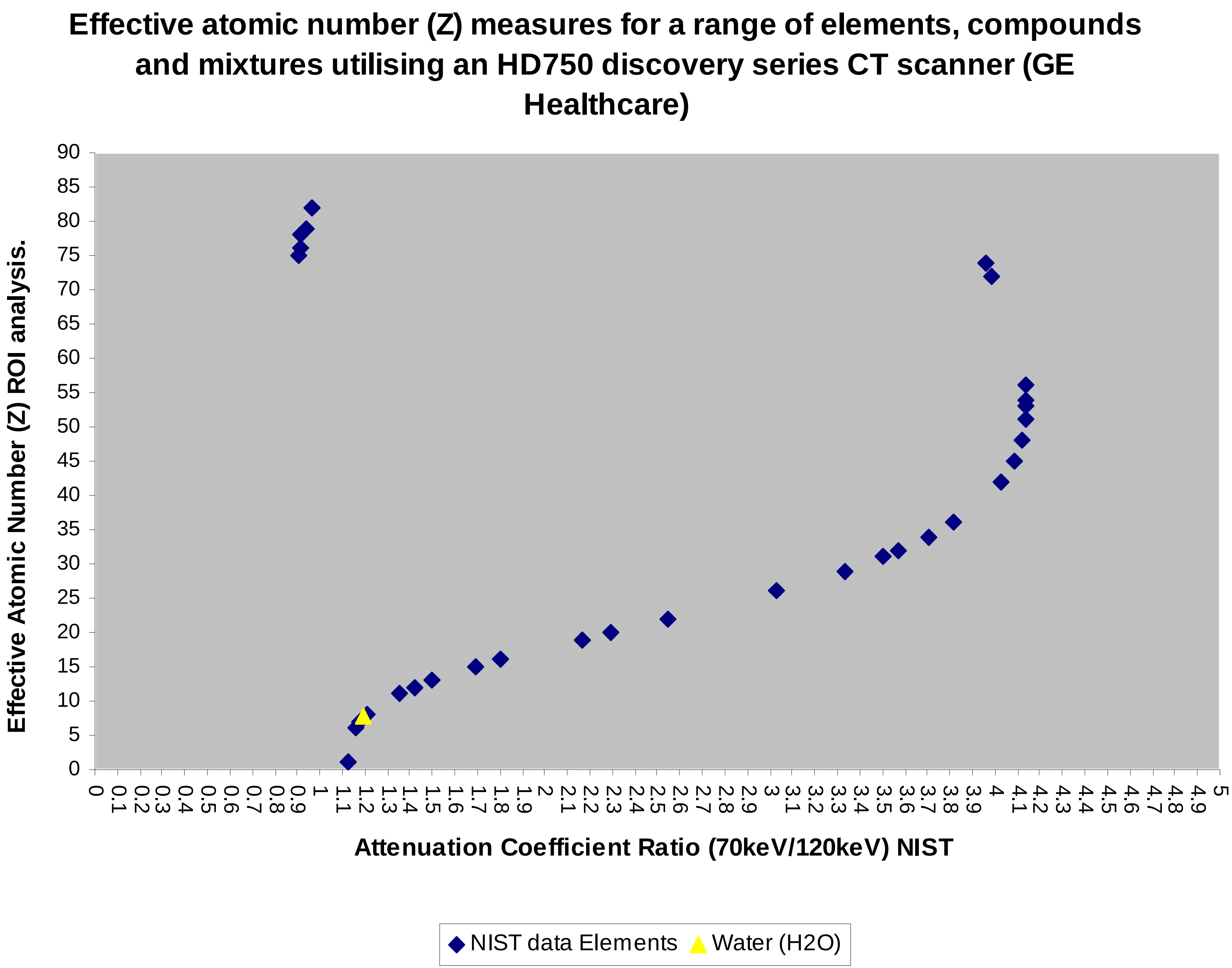


Materials:

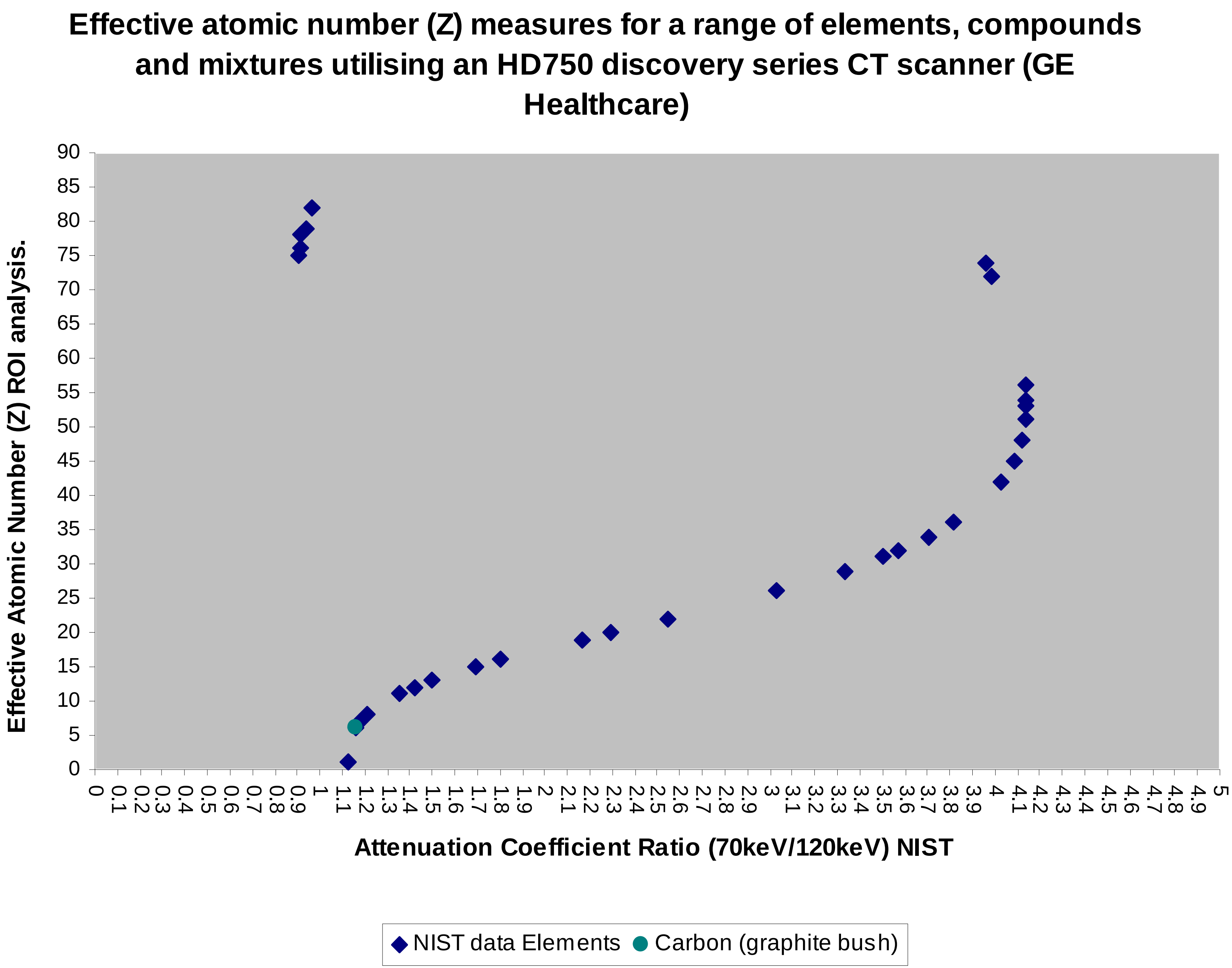
1. Water
2. Iodine
3. Carbon
4. Chalk



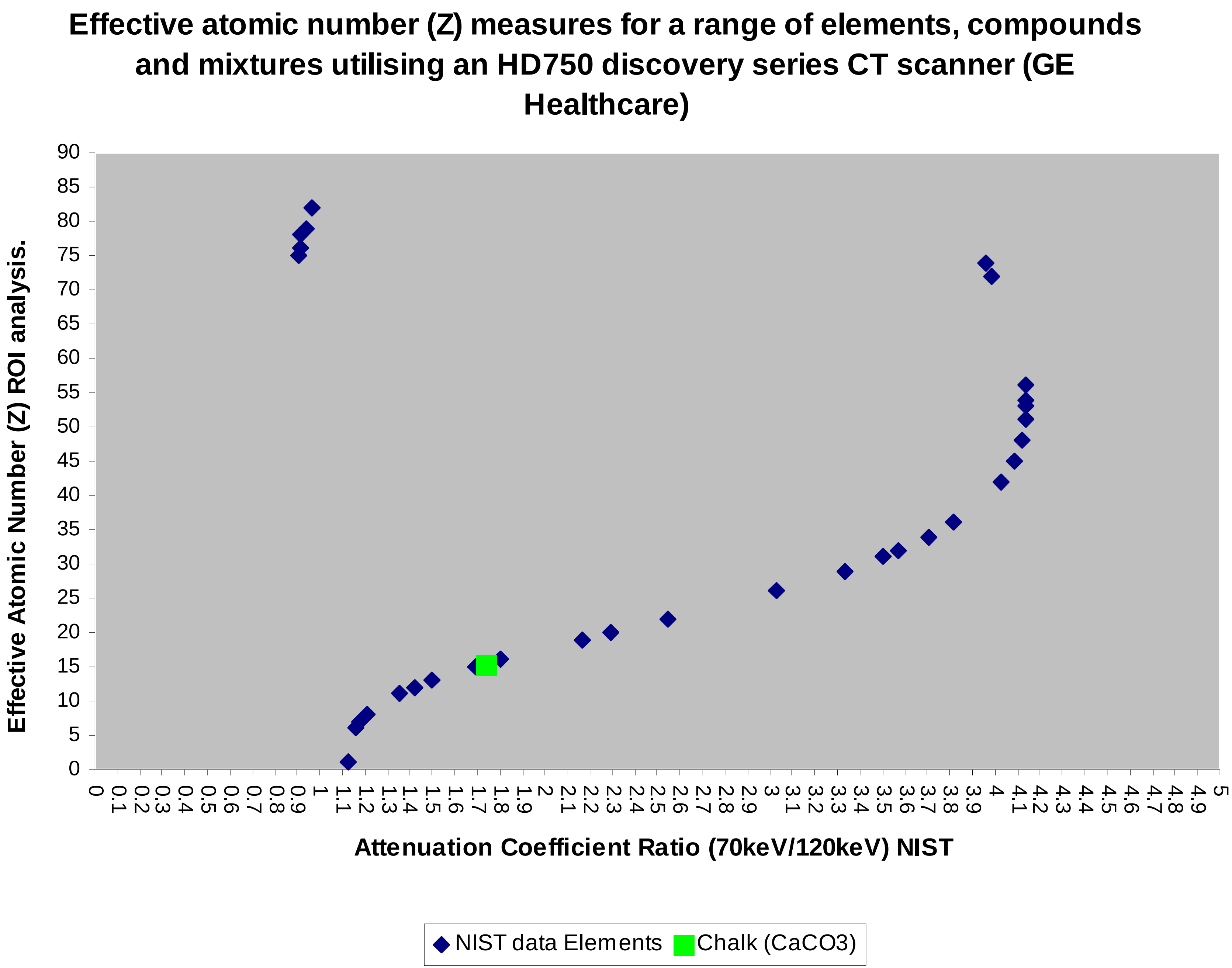
Effective atomic number (Z) measures for a range of elements, compounds and mixtures utilising an HD750 discovery series CT scanner (GE Healthcare)
Effective Atomic Number (Z) ROI analysis.
Attenuation Coefficient Ratio (70keV/120keV) NIST
Hf= 65
W = 70
Re = 72
Os = 74
Pt = 78
Au = 81
Pb = 88
K-edge of element disrupting attenuation ratio
NIST data Elements



Effective atomic number (Z) measures for a range of elements, compounds and mixtures utilising an HD750 discovery series CT scanner (GE Healthcare)
Effective Atomic Number (Z) ROI analysis.
Attenuation Coefficient Ratio (70keV/120keV) NIST
NIST data Elements
Water (H2O)



Effective atomic number (Z) measures for a range of elements, compounds and mixtures utilising an HD750 discovery series CT scanner (GE Healthcare)
Effective Atomic Number (Z) ROI analysis.
Attenuation Coefficient Ratio (70keV/120keV) NIST
NIST data Elements
Carbon (graphite bush)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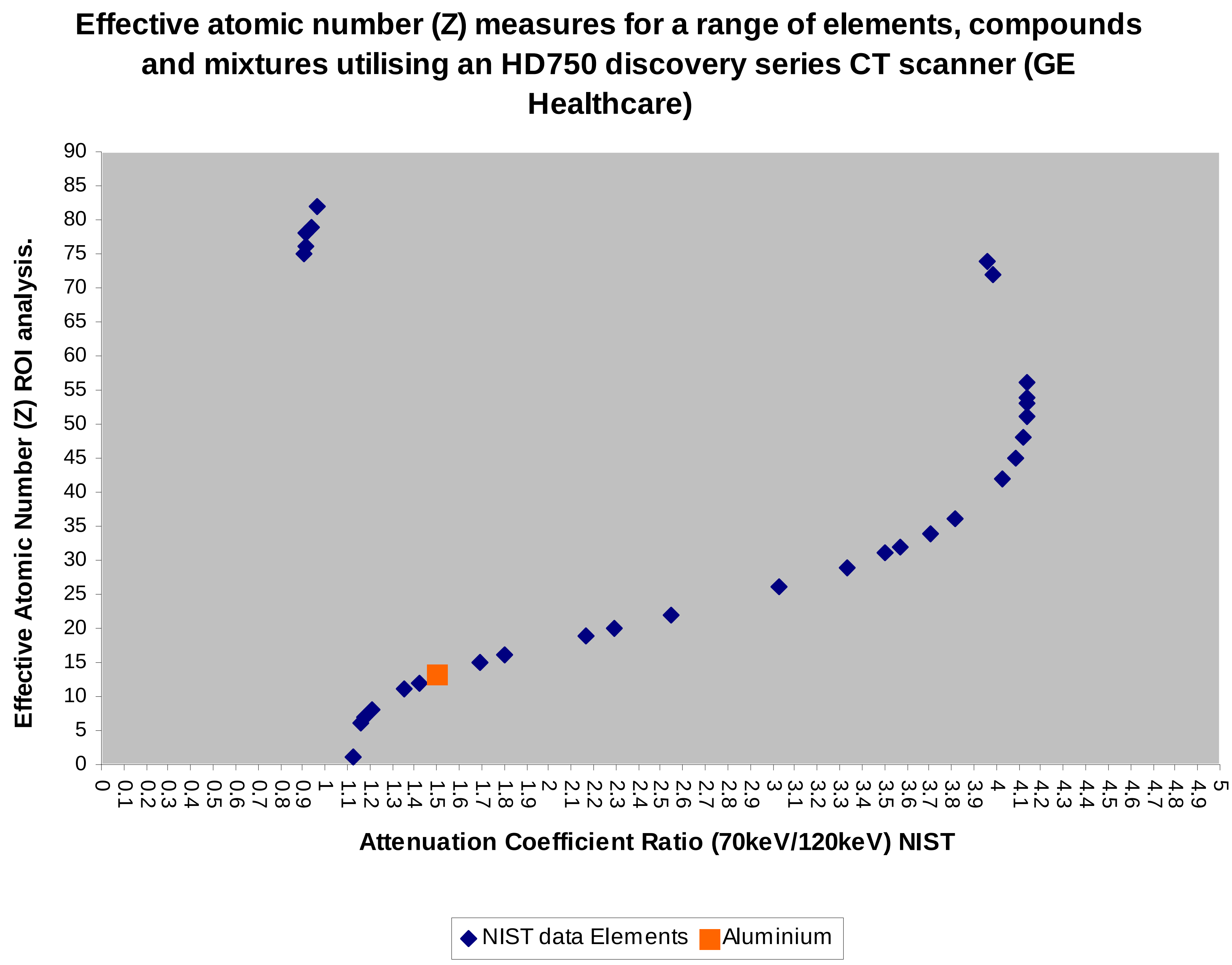
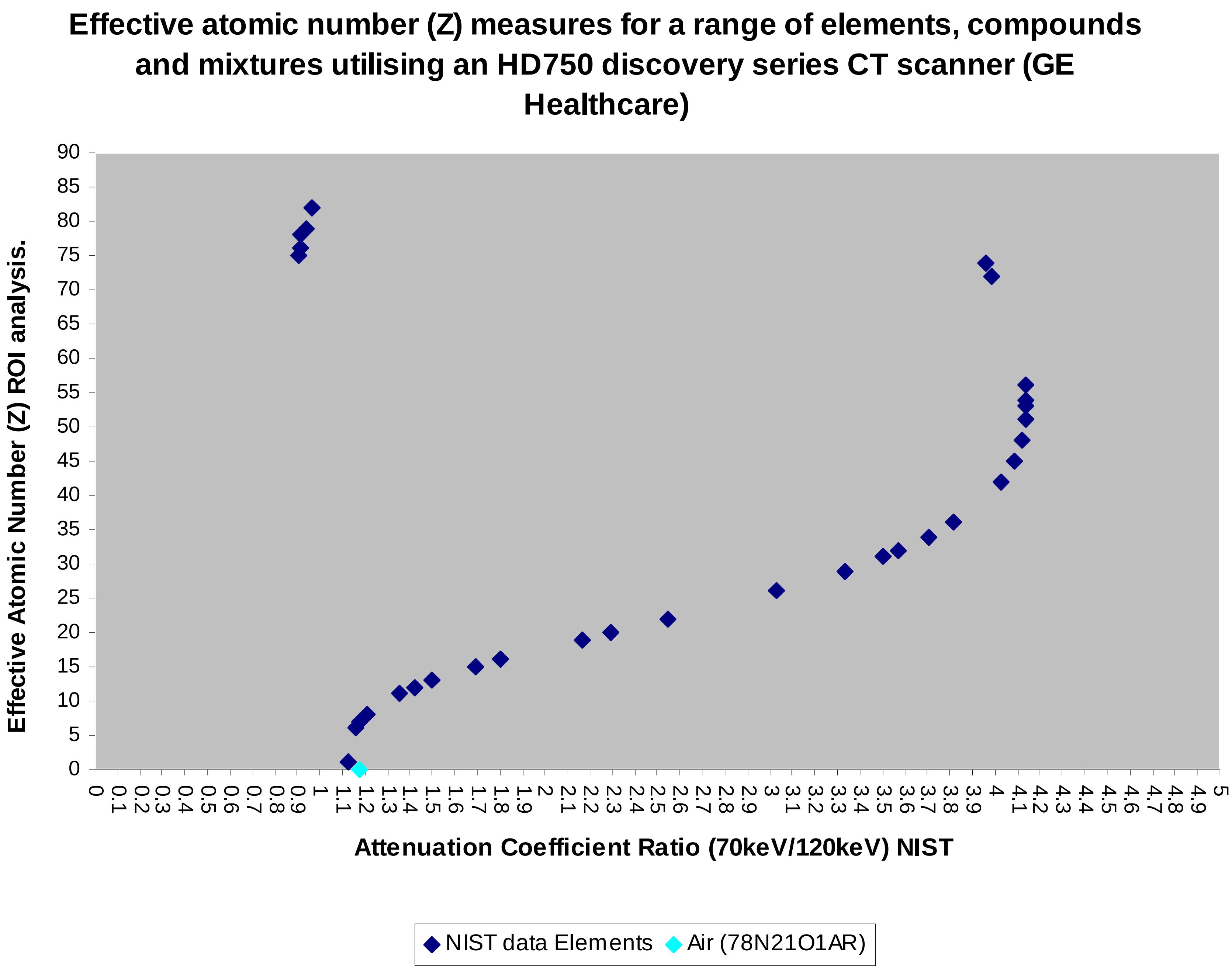
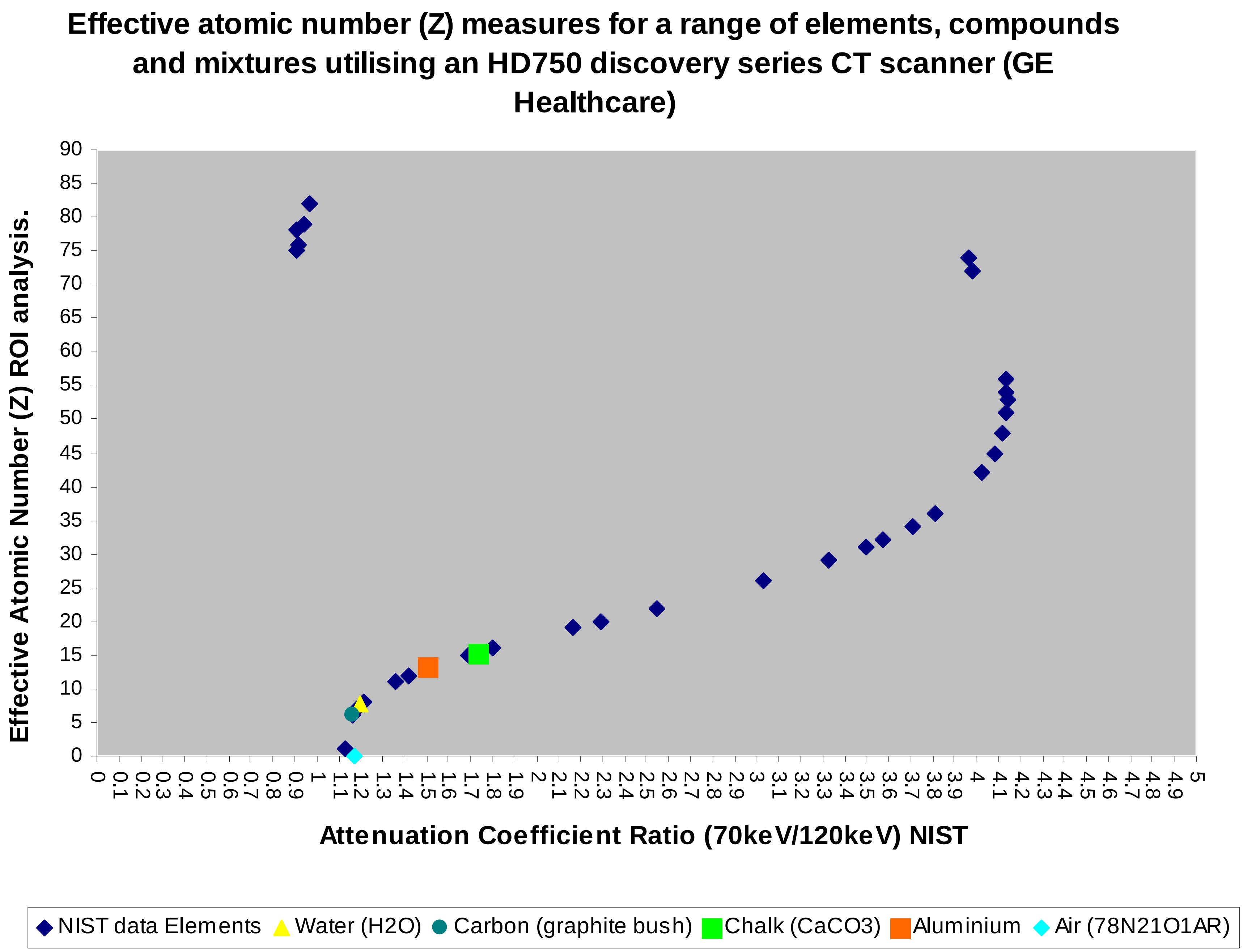
Effective Atomic Number (Z) ROI analysis.
Attenuation Coefficient Ratio (70keV/120keV) NIST
NIST data Elements
Chalk (CaCO3)

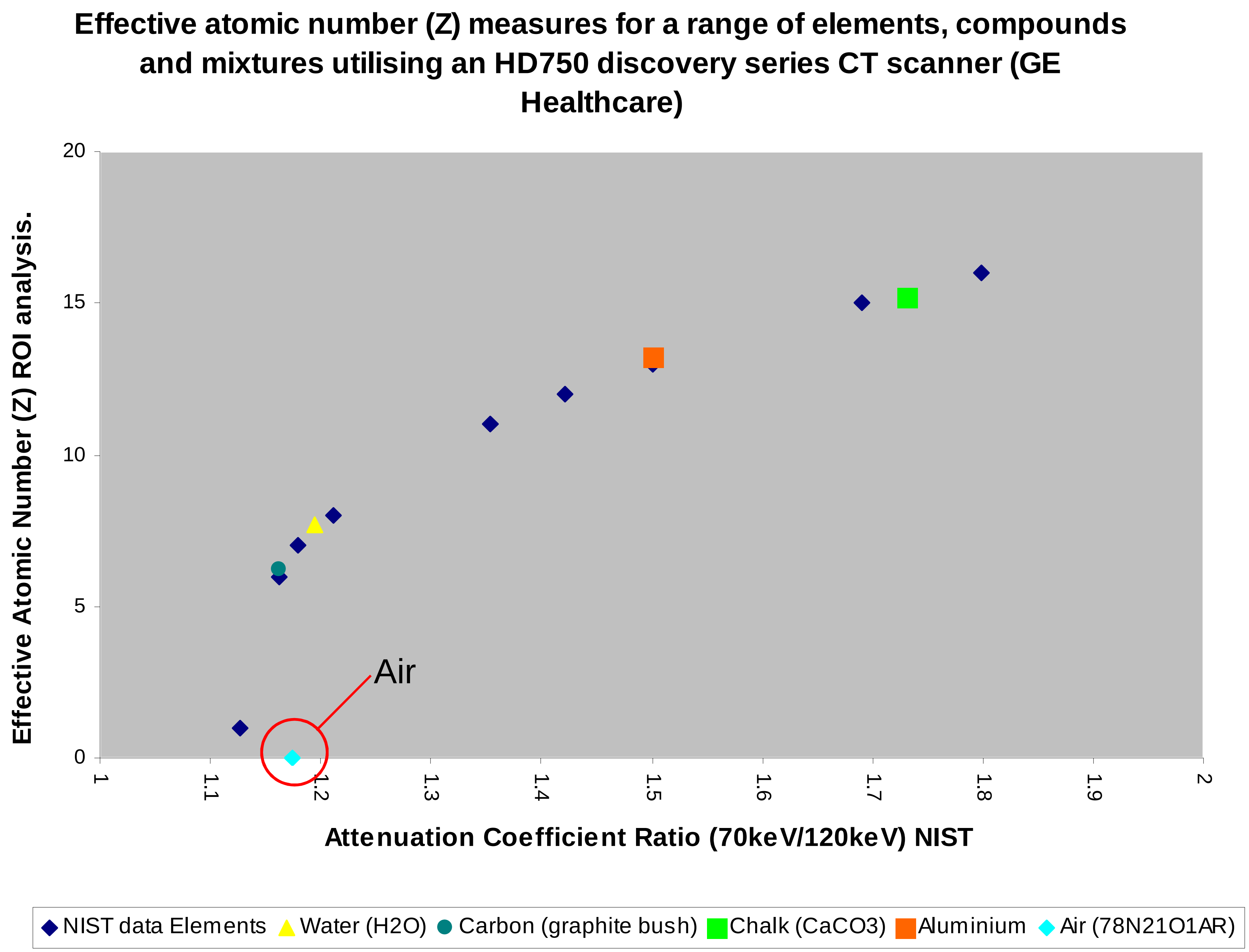


Effective atomic number (Z) measures for a range of elements, compounds and mixtures utilising an HD750 discovery series CT scanner (GE Healthcare)
Effective Atomic Number (Z) ROI analysis.
Attenuation Coefficient Ratio (70keV/120keV) NIST
NIST data Elements
Aluminium

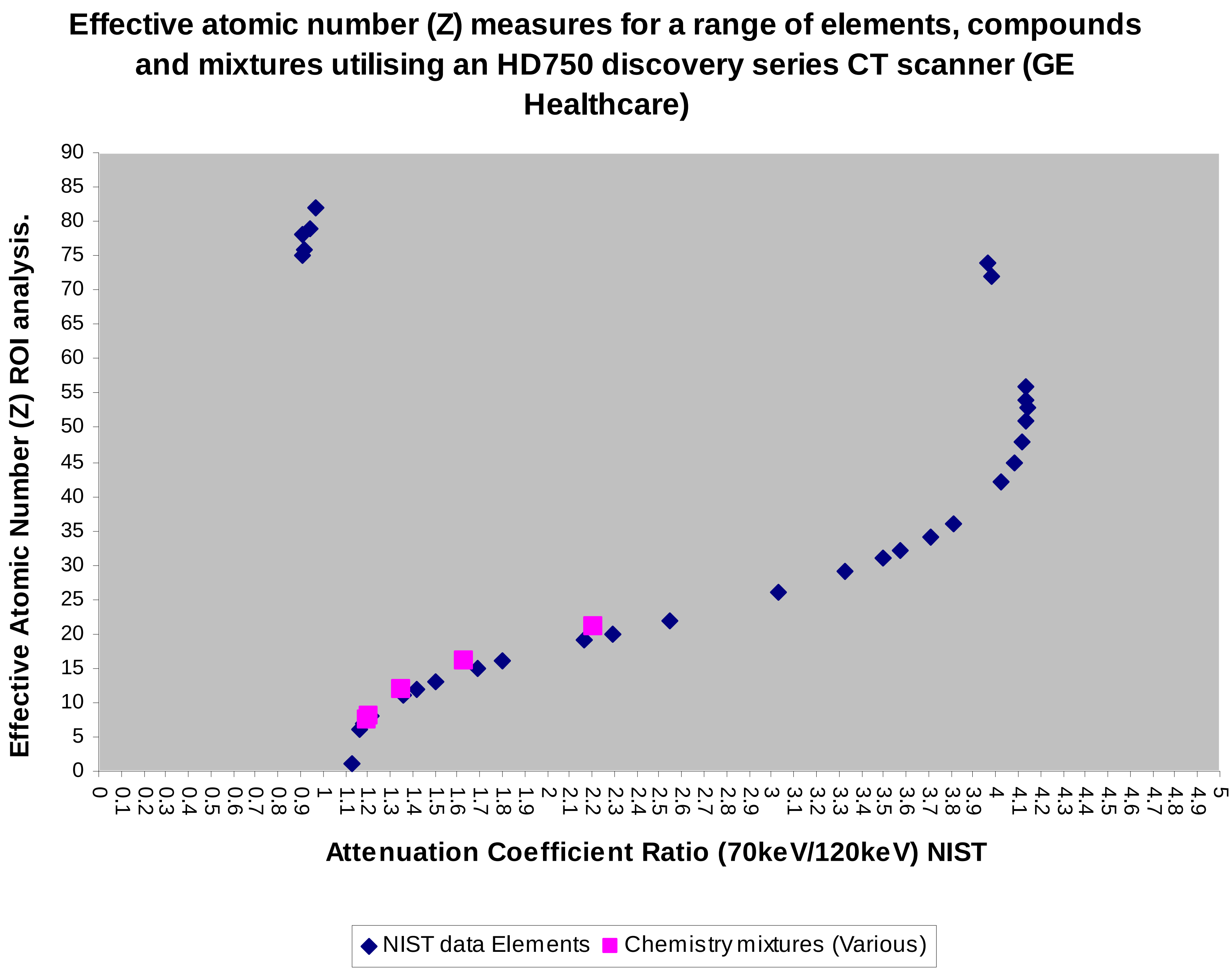

Effective atomic number (Z) measures for a range of elements, compounds and mixtures utilising an HD750 discovery series CT scanner (GE Healthcare)
Effective Atomic Number (Z) ROI analysis.
Attenuation Coefficient Ratio (70keV/120keV) NIST
NIST data Elements
Air (78N21O1AR)



Effective atomic number (Z) measures for a range of elements, compounds and mixtures utilising an HD750 discovery series CT scanner (GE Healthcare)
Effective Atomic Number (Z) ROI analysis.
Attenuation Coefficient Ratio (70keV/120keV) NIST
NIST data Elements
Water (H2O)
Carbon (graphite bush)
Chalk (CaCO3)
Aluminium
Air (78N21O1AR)



Effective atomic number (Z) measures for a range of elements, compounds and mixtures utilising an HD750 discovery series CT scanner (GE Healthcare)
Effective Atomic Number (Z) ROI analysis.
0
5
10
15
20
1
1.1
1.2
1.3
1.4
1.5
1.6
1.7
1.8
1.9
2
Air
Attenuation Coefficient Ratio (70keV/120keV) NIST
NIST data Elements
Water (H2O)
Carbon (graphite bush)
Chalk (CaCO3)
Aluminium
Air (78N21O1AR)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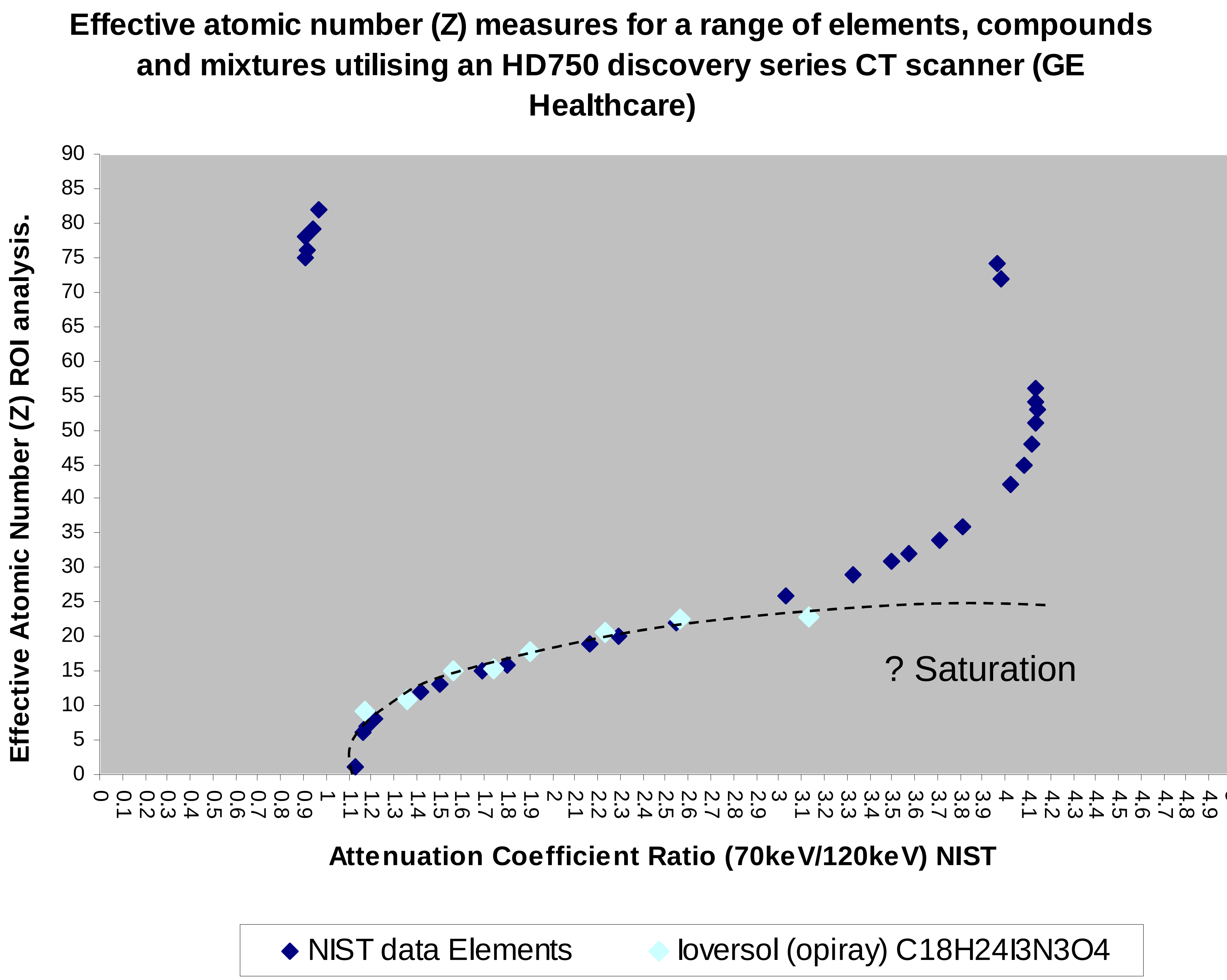
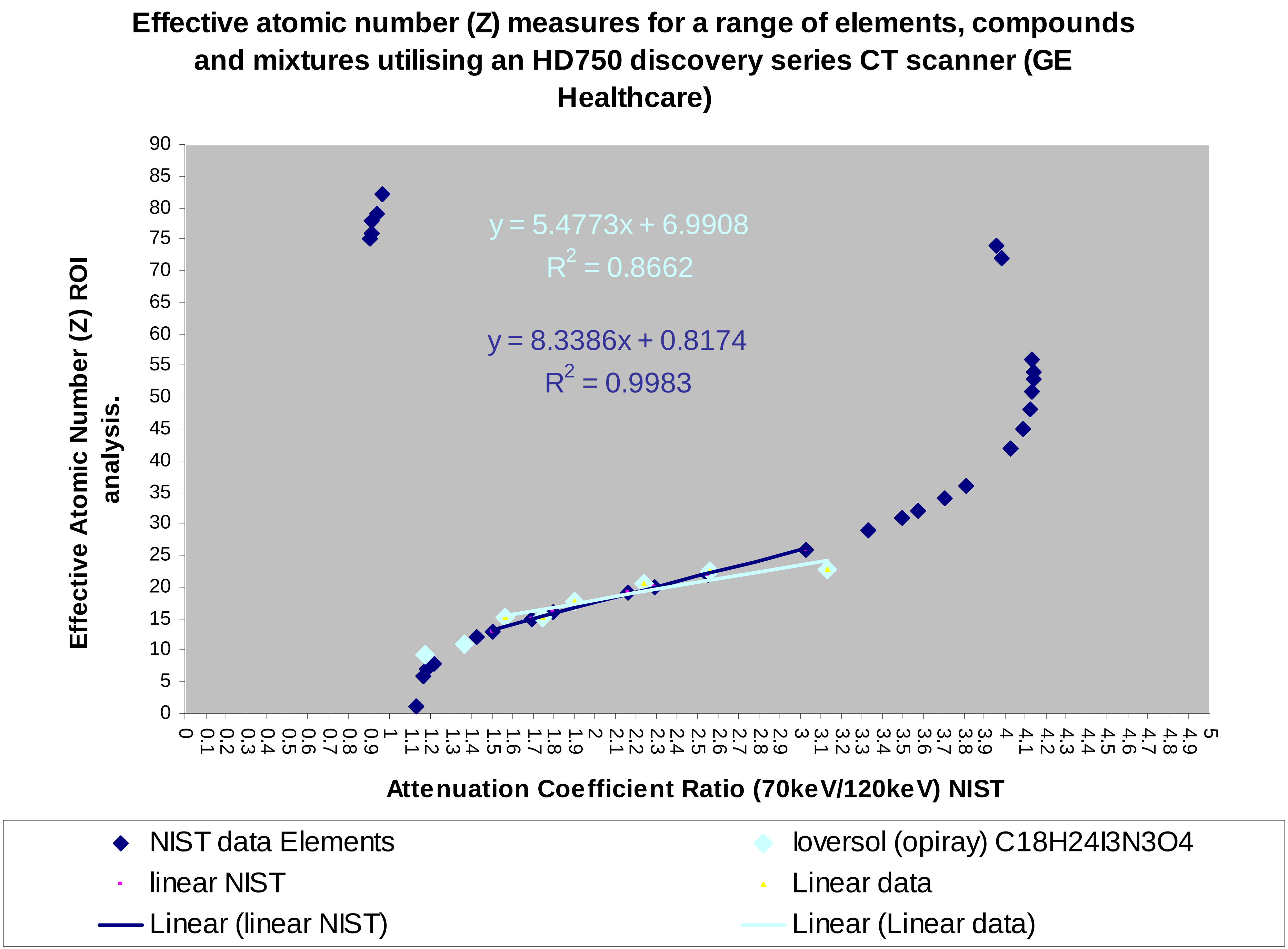
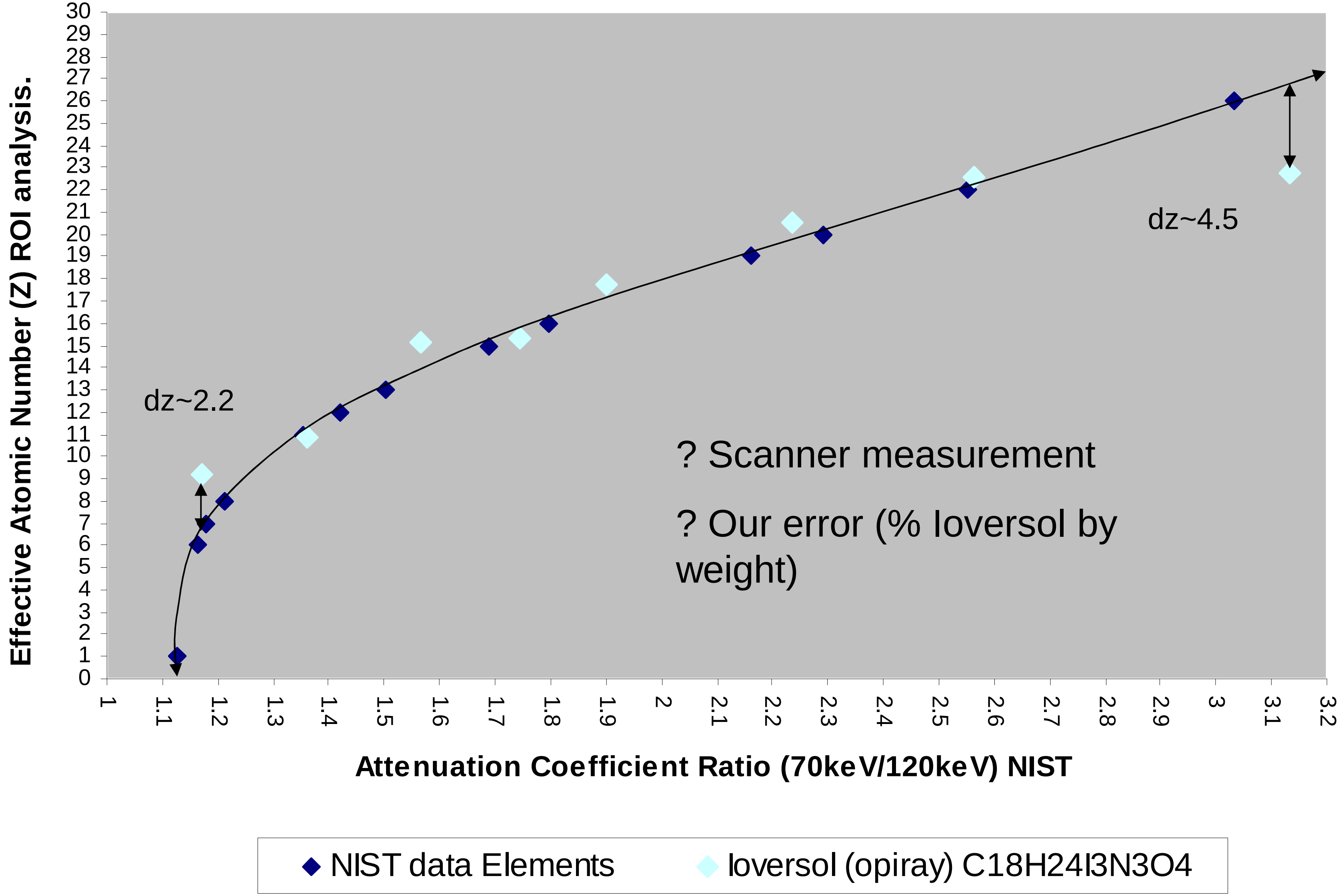
Effective Atomic Number (Z) ROI analysis.
Attenuation Coefficient Ratio (70keV/120keV) NIST
NIST data Elements
Chemistry mixtures (Various)

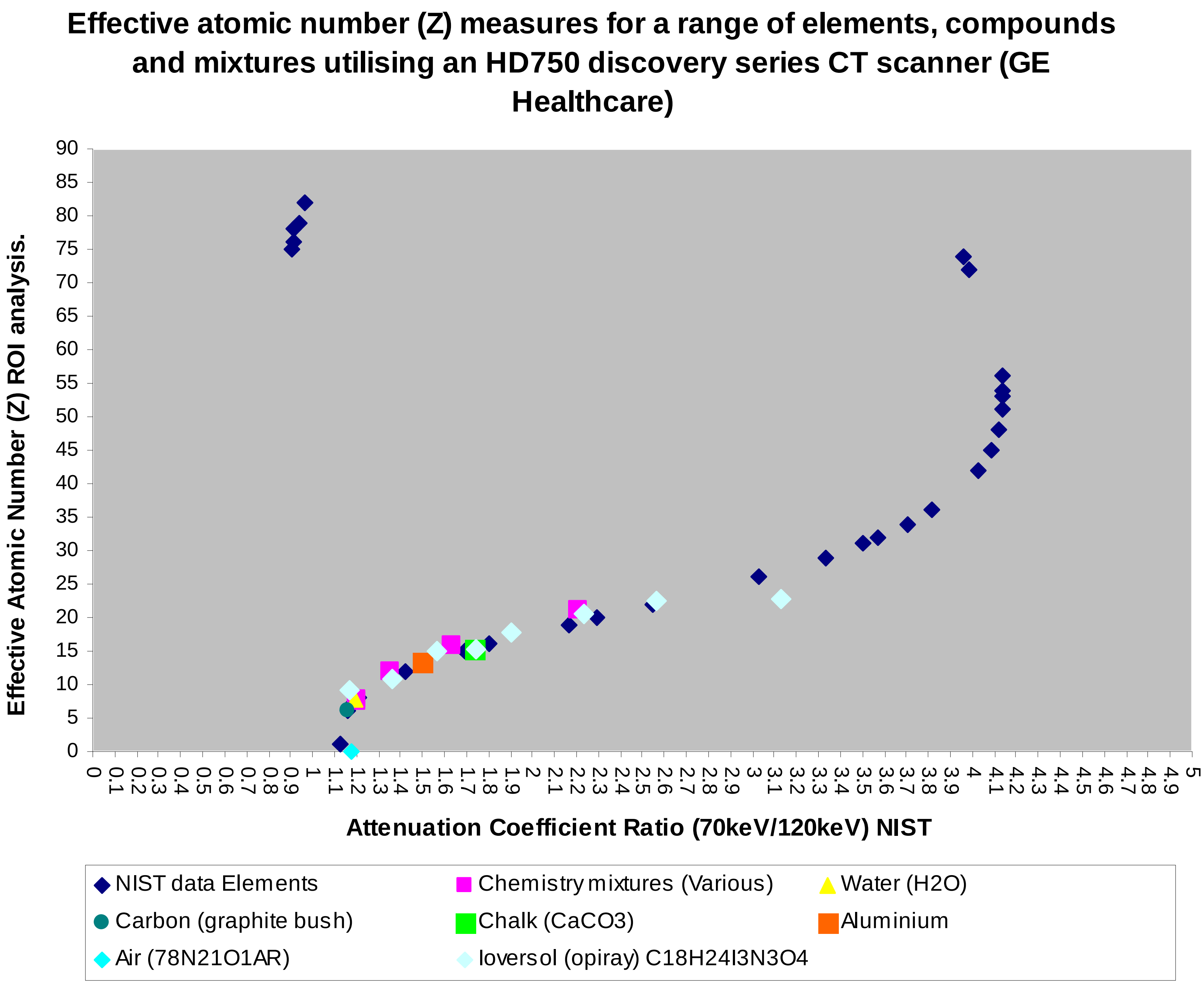

Effective atomic number (Z) measures for a range of elements, compounds and mixtures utilising an HD750 discovery series CT scanner (GE Healthcare)
Effective Atomic Number (Z) ROI analysis.
Attenuation Coefficient Ratio (70keV/120keV) NIST
? Saturation
NIST data Elements
Ioversol (opiray) C18H24I3N3O4



Effective atomic number (Z) measures for a range of elements, compounds and mixtures utilising an HD750 discovery series CT scanner (GE Healthcare)
y = 5.4773x + 6.9908
R2 = 0.8662
y = 8.3386x + 0.8174
R2 = 0.9983
Effective Atomic Number (Z) ROI analysis.
Attenuation Coefficient Ratio (70keV/120keV) NIST
NIST data Elements
linear NIST
Linear (linear NIST)
Ioversol (opiray) C18H24I3N3O4
Linear data
Linear (Linear data)

Effective atomic number (Z) measures for a range of elements, compounds and mixtures utilising an HD750 discovery series CT scanner (GE Healthcare)

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Effective Atomic Number (Z) ROI analysis.
Attenuation Coefficient Ratio (70keV/120keV) NIST
NIST data Elements
Chemistry mixtures (Various)
Water (H2O)
Carbon (graphite bush)
Chalk (CaCO3)
Aluminium
Air (78N21O1AR)
Ioversol (opiray) C18H24I3N3O4

Discussion

- With the exception of air, for the elements scanned, the CT scanner's measure of atomic number was in reasonable agreement with known elements.
- Chemistry mixtures and iodine concentrations broadly followed the expected "signature" curve.
- Further work is required to assess a possible saturation in scanner measured Z for high iodine concentrations.
- Further work is required to calculate total measurement uncertainty before firm conclusions can be made.

A Question…

- Based on these early measurements, would I expect the scanner to accurately measure a small change in Z within a small ROI over a kidney stone?

THE END