SCA 2017 – Vienna, Austria

Core Imaging - Short Course
Gamma, X-ray & CT imaging

Lloyd's Register

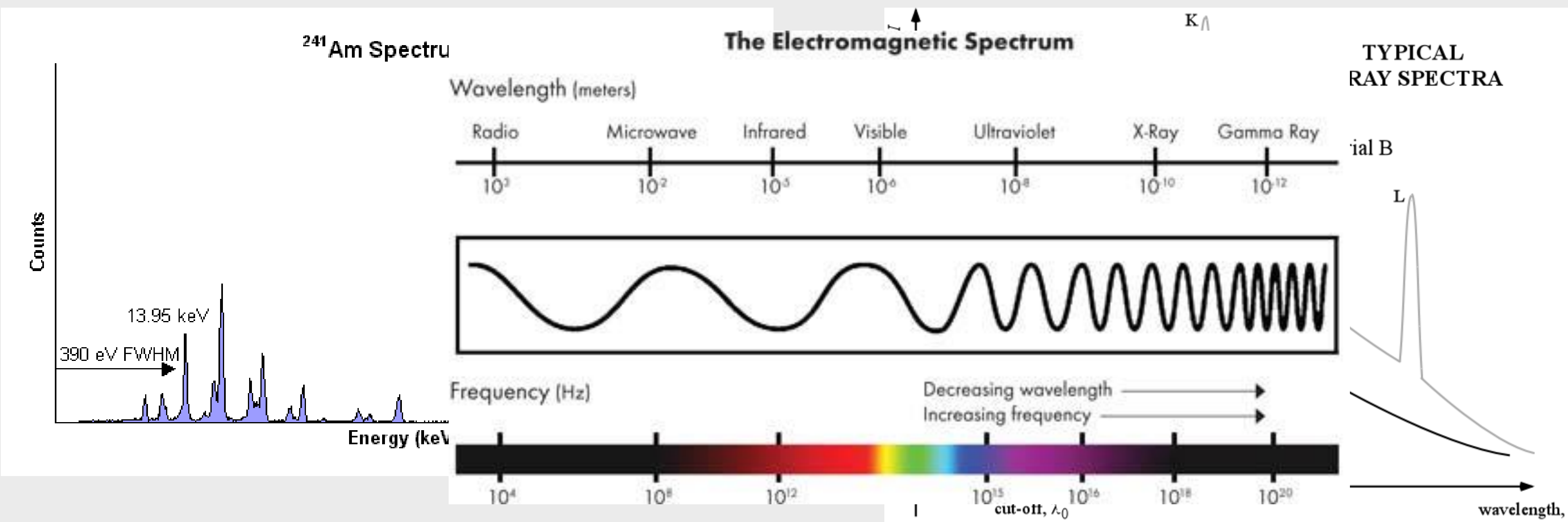
Working together
for a safer world

1D to 3D Imaging Methods

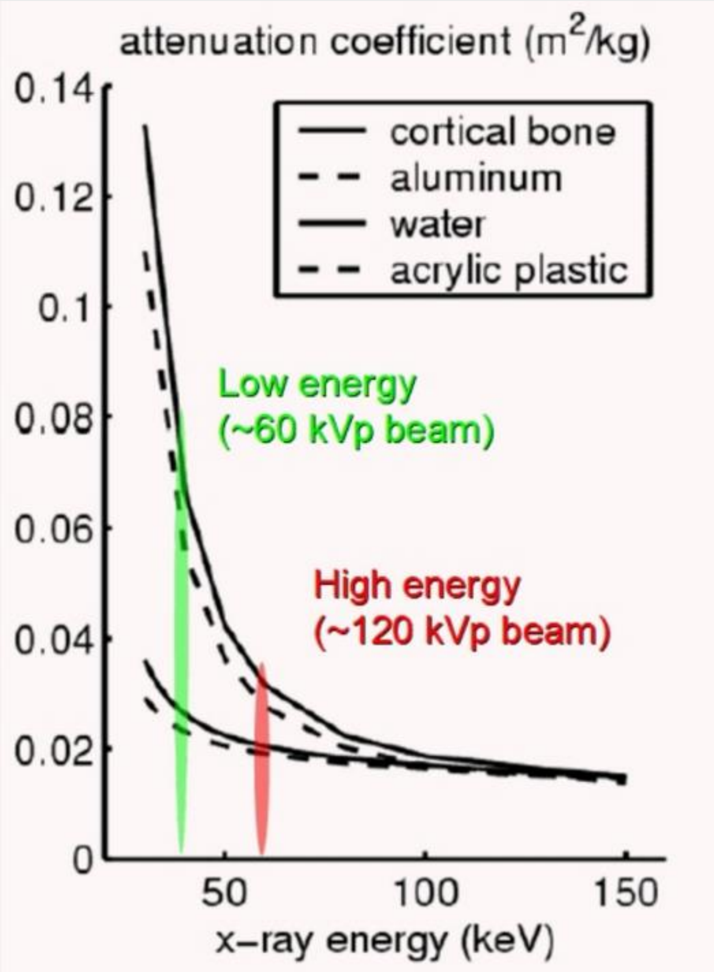
- Gamma ray, x-ray and CT
  - Gamma vs. x-ray
  - Gamma log
  - CT
    - Note regarding grey-scale images
    - Uses: description, analysis, assessment
- Beer-Lambert Law
  - 1D + time
    - Saturation determination
    - Considerations

Gamma versus x-ray

- Gamma and x-ray are high energy electromagnetic rays
  - No precise distinction between the two
  - Gamma generally higher energy, generally more unique spectral signal
  - Gamma usually from nuclear decay, x-ray from electron excitation



Attenuation



- Gamma / x-rays will be slowed (attenuated) as they pass through and interact with a material
- Different materials exhibit different levels of attenuation
  - Materials exhibit lower attenuation coefficients to higher energy rays
- Thicker material, will exponentially attenuate (block) more rays and detected counts is given by

$$I = I_0 \, e^{-\mu x}$$

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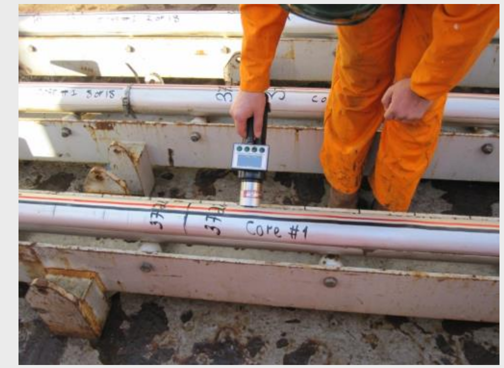
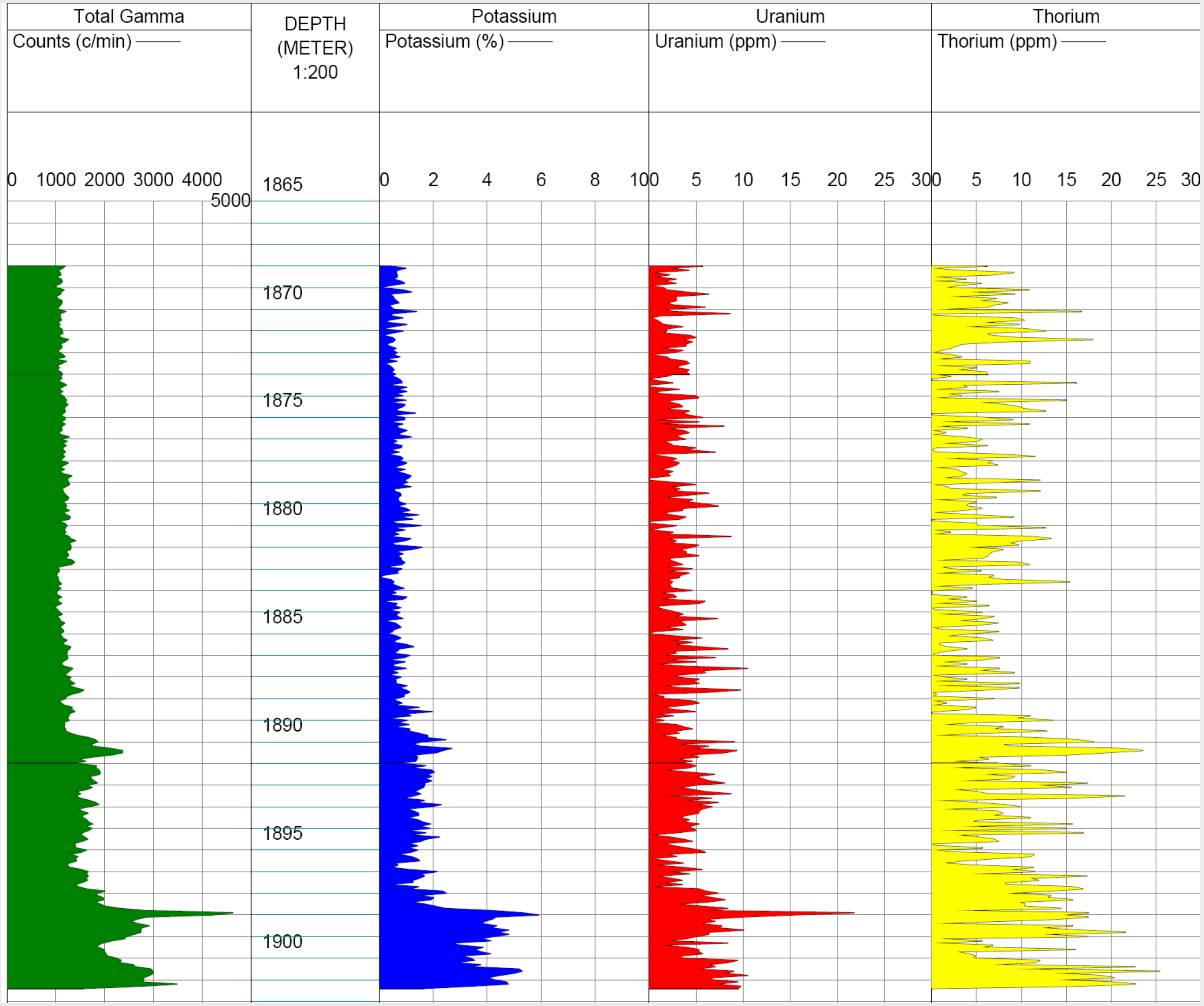
Core Gamma Ray Logging

- Wellsite and/or Lab
- Mainly for core-log depth shifting
- Total and spectral gamma
  - uranium/potassium/thorium ratios
- Equipment
  - conveyor belt (1 ft/min, 18 m/h)
  - NaI detector (shielded)
  - analyser system
  - computer



Core Gamma Example



1D to 3D Imaging Methods

- Gamma ray, x-ray and CT
  - Gamma vs. x-ray
  - Gamma log
  - CT – spatially resolved x-ray measurements
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CT scanning – grey-scale image settings

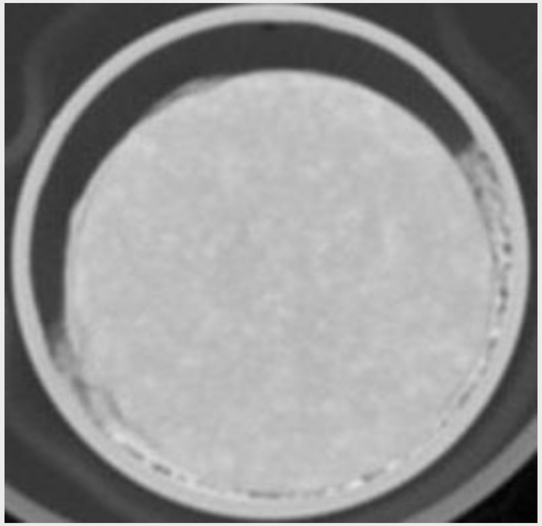
- Hounsfield Unit = measures radiodensity
  - function of attenuation coefficients

$$HU = 1000 \frac{\mu - \mu_w}{\mu_w - \mu_a}$$

  - Air: HU = -1000
  - Water: HU = 0

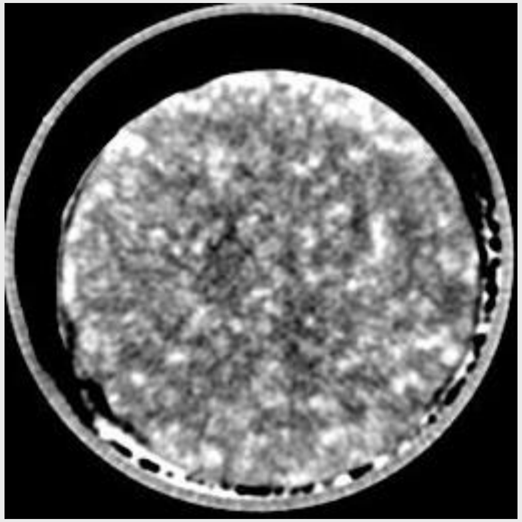
WL(or WC) = Centre HU setting
WW = Width HU Setting

Standard CT setting
WC-1000, WW-4096



Range = -1048 to 3048

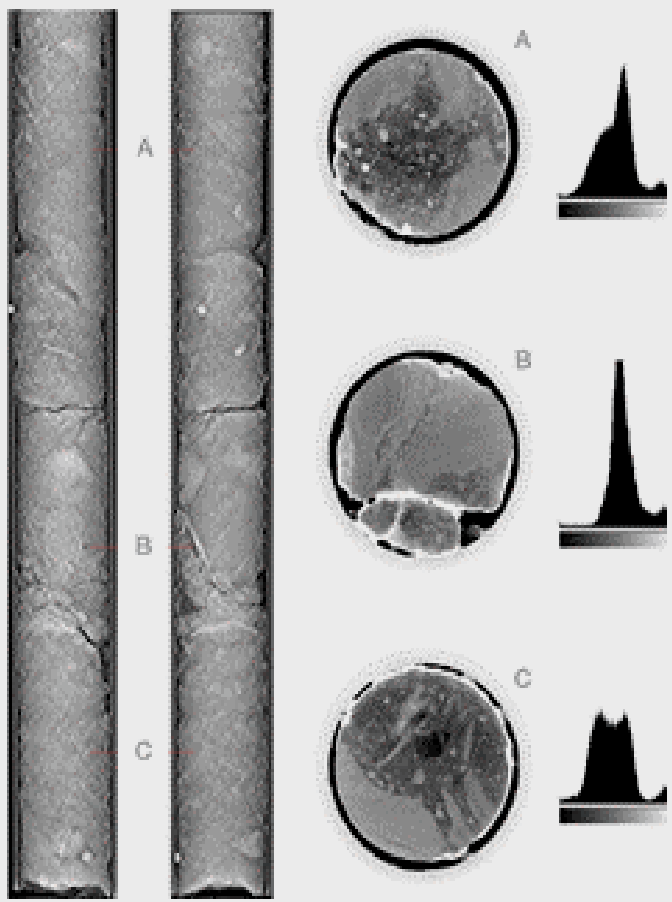
Core setting
WC-2000, WW-400

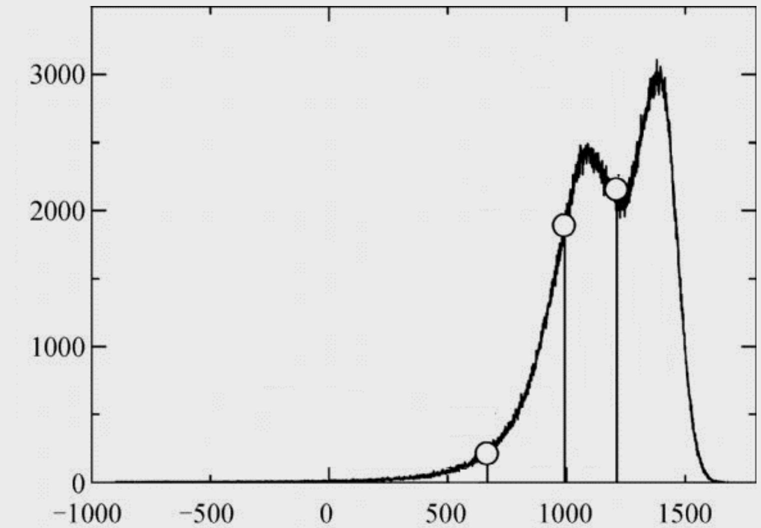


Range = 1800 to 2200

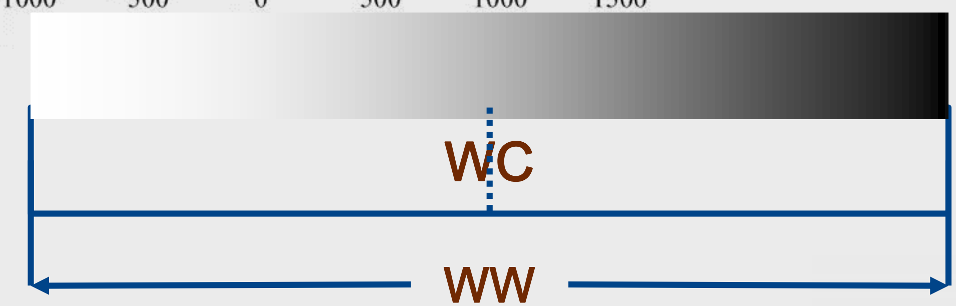
CT scanning – grey-scale image settings

Different density profiles will require different HU image settings

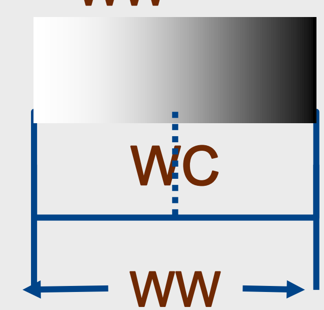




Standard Equipment Setting



Optimised Core Setting

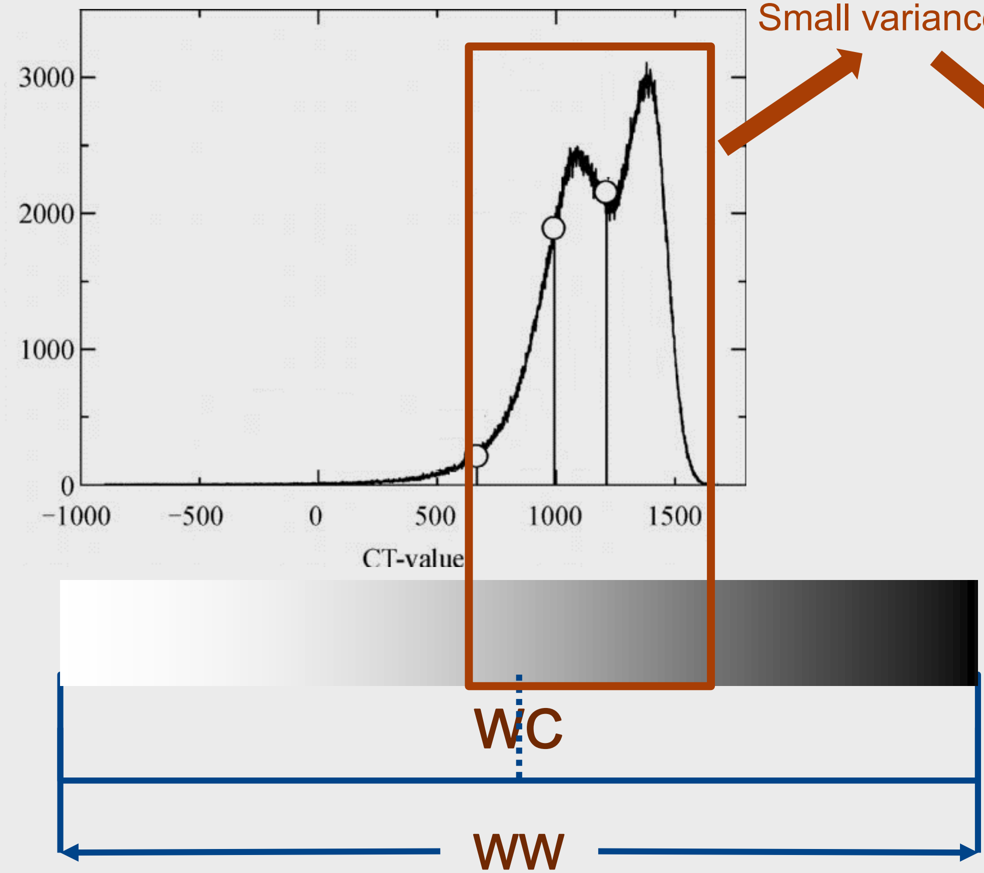


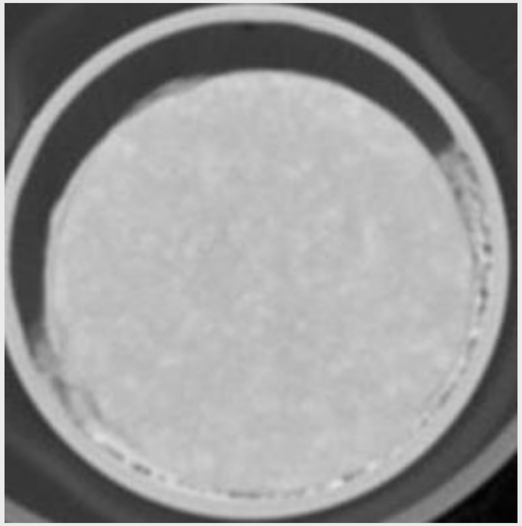
CT scanning – grey-scale image settings

Standard CT equipment setting

WC = 1000
WW = 4096

Core density in the middle of the grey-scale
Small variance in observed image

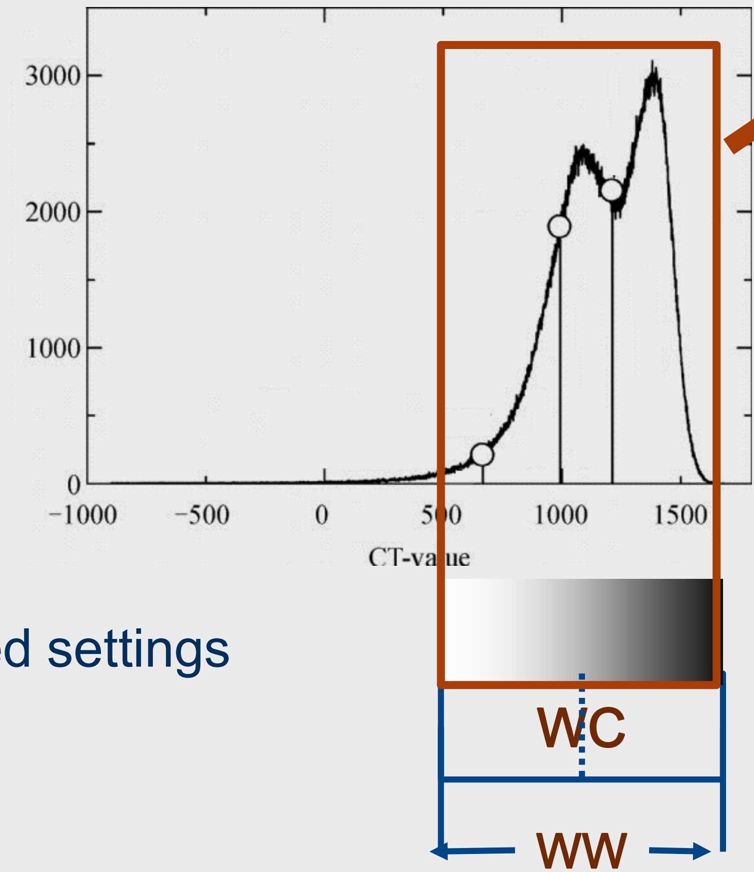


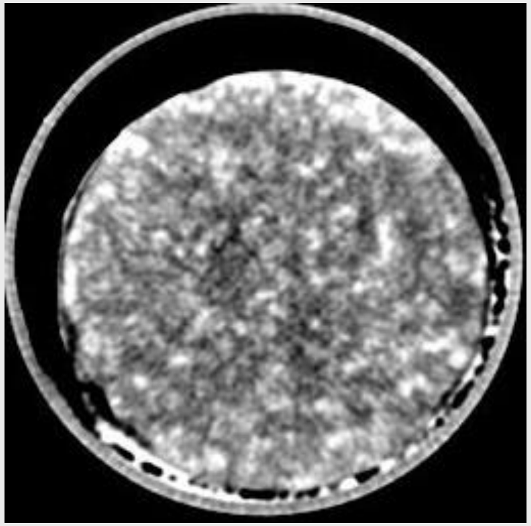


CT scanning – grey-scale image settings

- SCA 2013-004 recommends initial assessment using WW=200

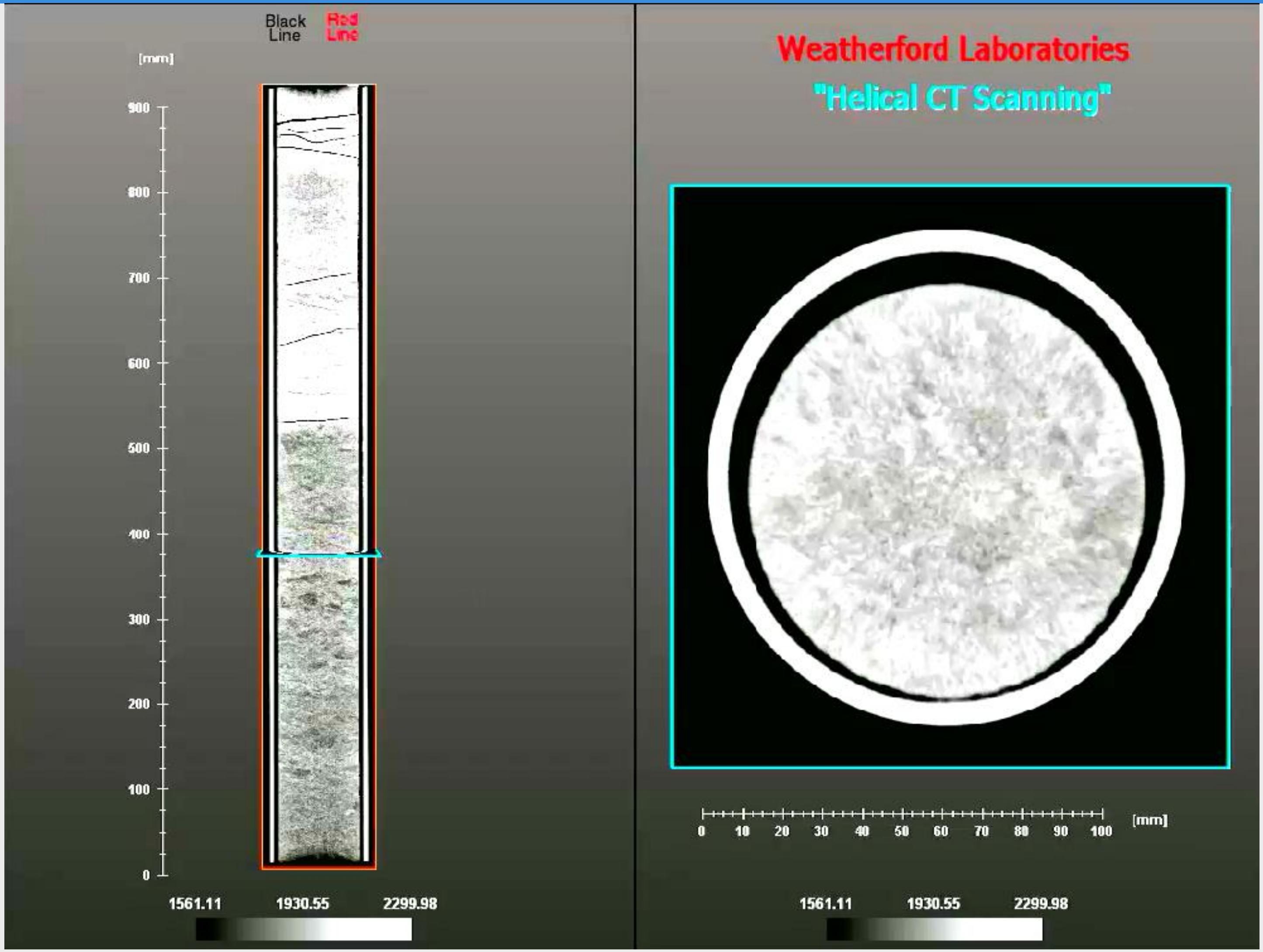
Grey-scale optimised from lowest to highest density
Variance in observed image – white to black



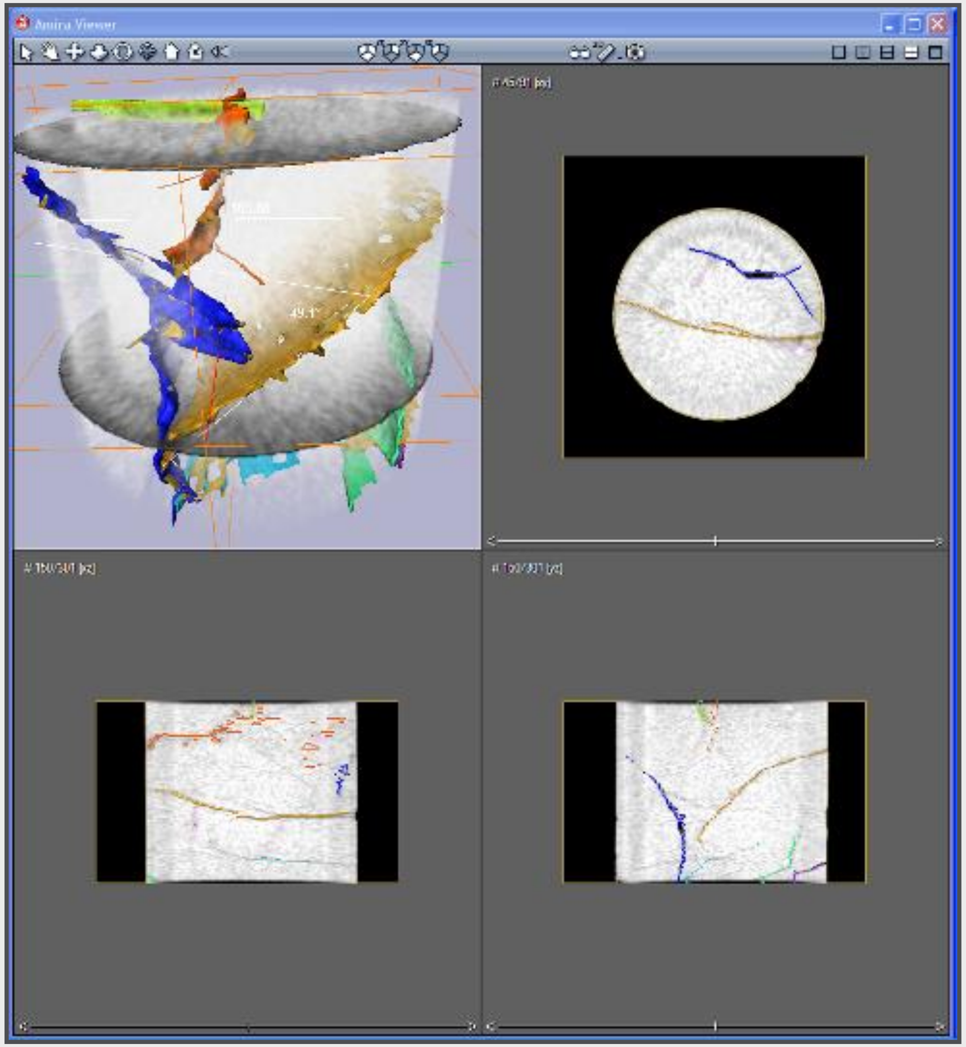


Optimised settings

Helical CT scan – 3D



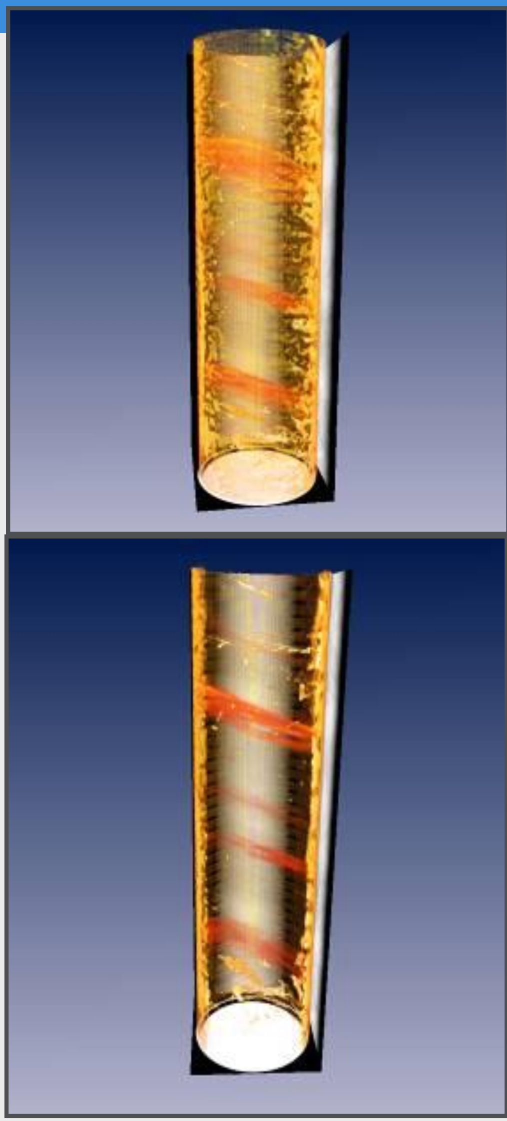
Helical CT scan – 3D analysis

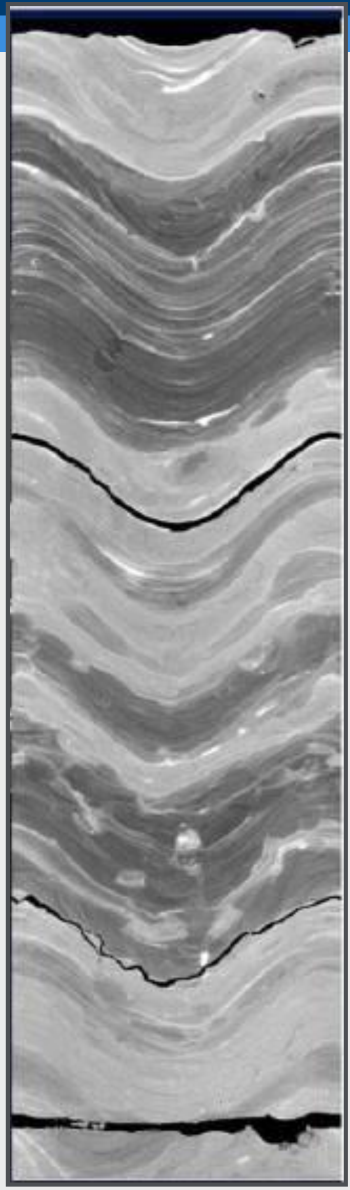


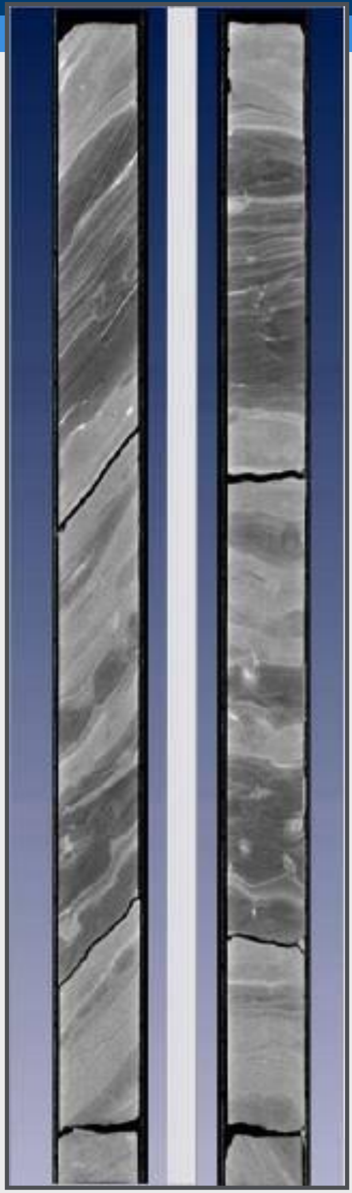
- 3D scans allow various analytics

- Feature Identification Options
- Each feature is extracted, named, and analyzed separately. For each feature, you can specify name, color, and visibility options.

Helical CT scan – 3D analysis

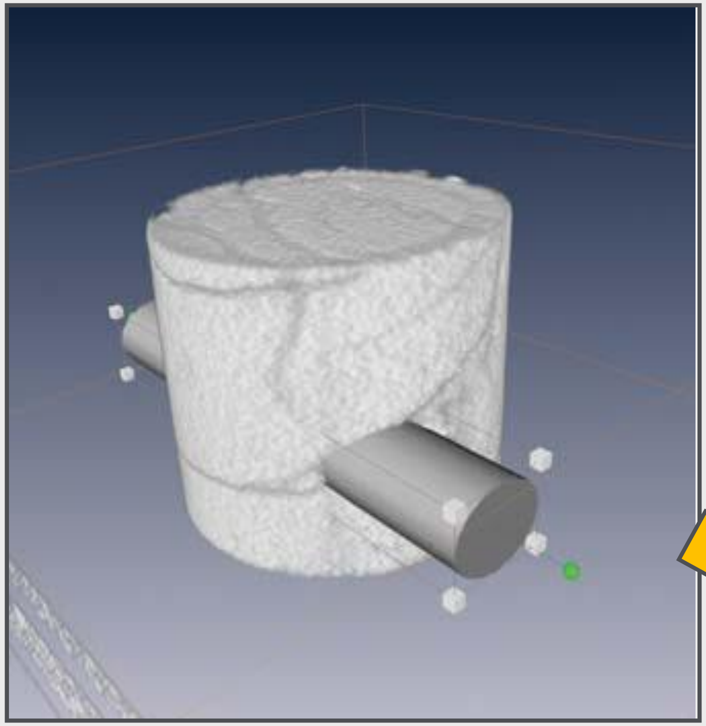




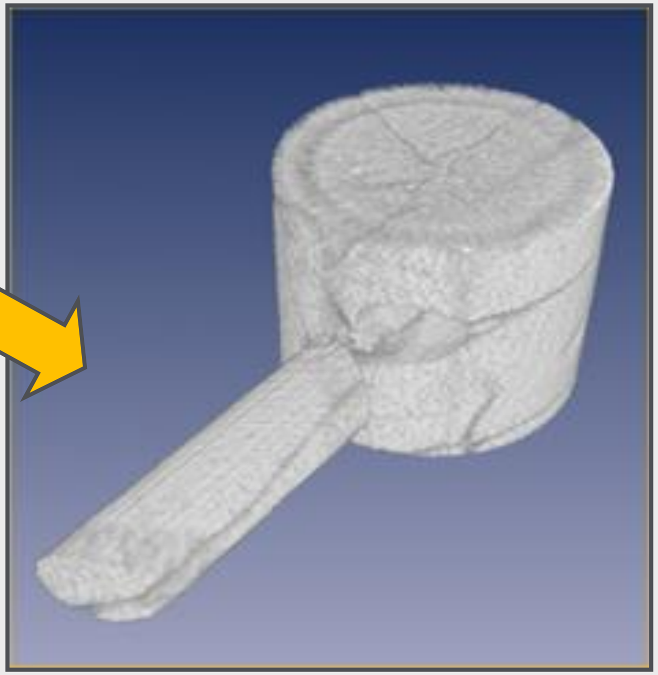


- Orientation
- Dip
- Strike
- Image log correlation

Helical CT scan – 3D analysis



- Virtual Plug Extraction
  - Assess plug viability before acquiring



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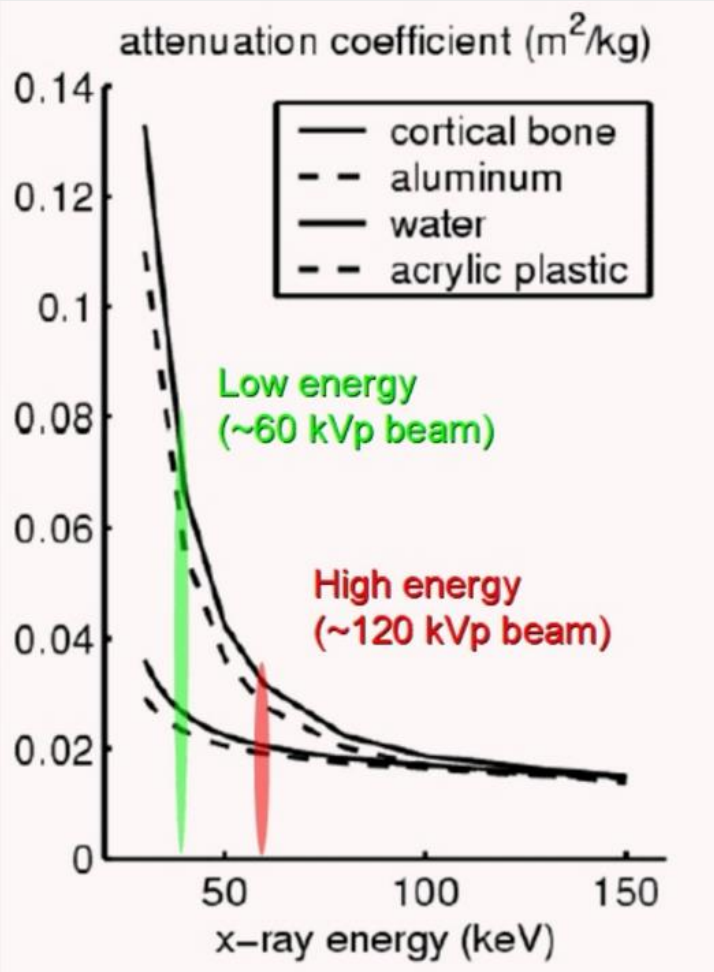
  - 1D + time (in situ saturation monitoring [ISSM])
    - Saturation determination
    - Considerations

Attenuation – Beer-Lambert Law



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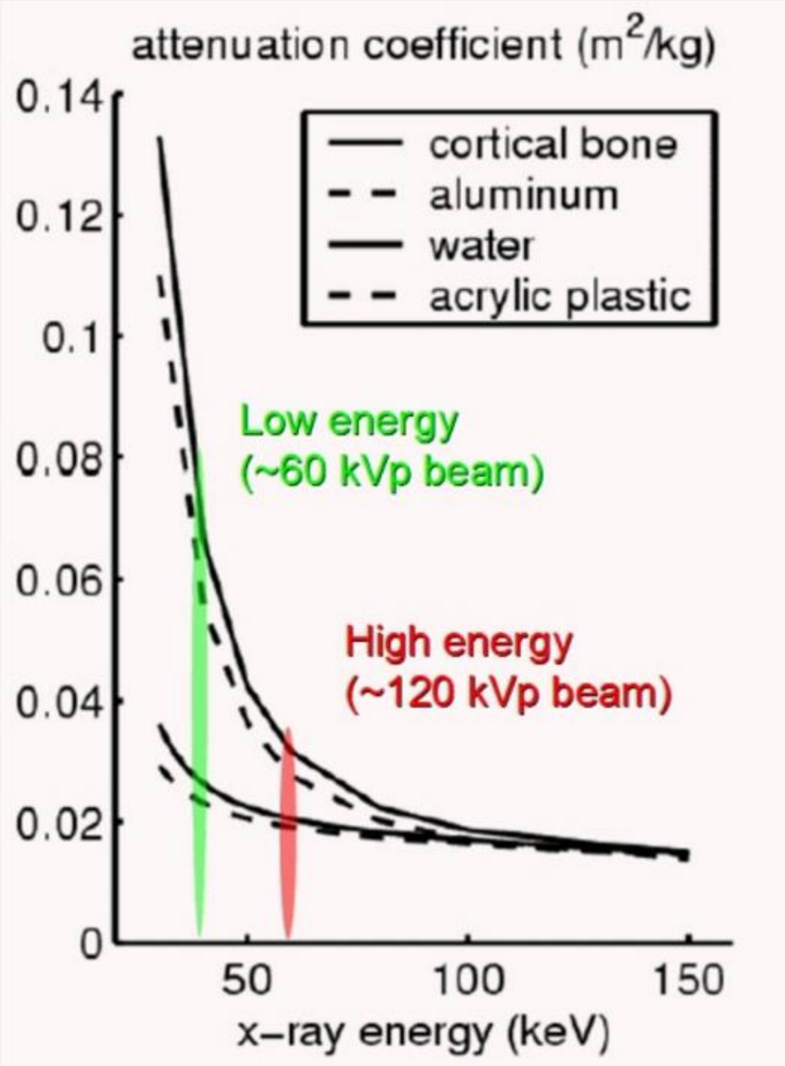
In situ saturation monitoring (ISSM)

- For a composite material, total attenuation is the sum of the individual materials' attenuation coefficients and the saturation of each material
- For core samples
  - Core sample maintained in fixed position
  - Assume the rock matrix is unchanging
  - Changes in attenuation (detected counts) = change in fluid saturation
  - Calibration performed Sw = 0, Sw =1 and intermediate values given by:

$$Sw = \frac{\ln(I) - \ln(I_{So})}{\ln(I_{Sw}) - \ln(I_{So})} = \frac{\ln\left({}^{I}/_{I_{So}}\right)}{\ln\left({}^{I_{Sw}}/_{I_{So}}\right)}$$

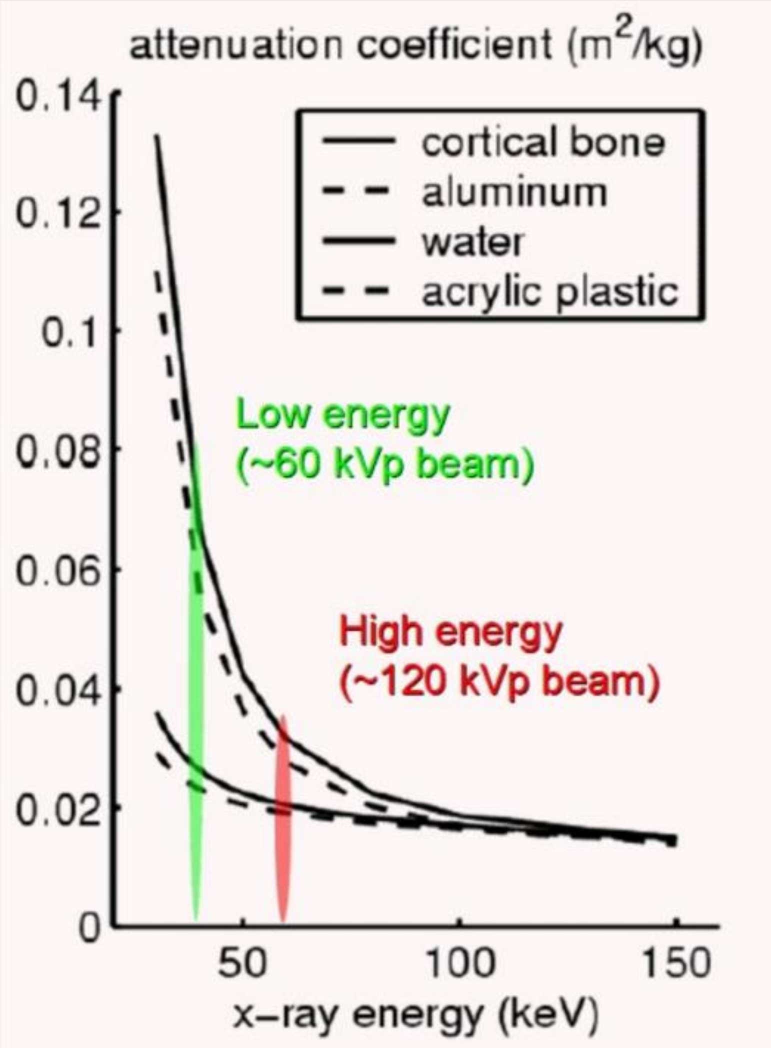
    - I_{Sw} is Sw=1, I_{So} is Sw = 0

In situ saturation monitoring (ISSM)



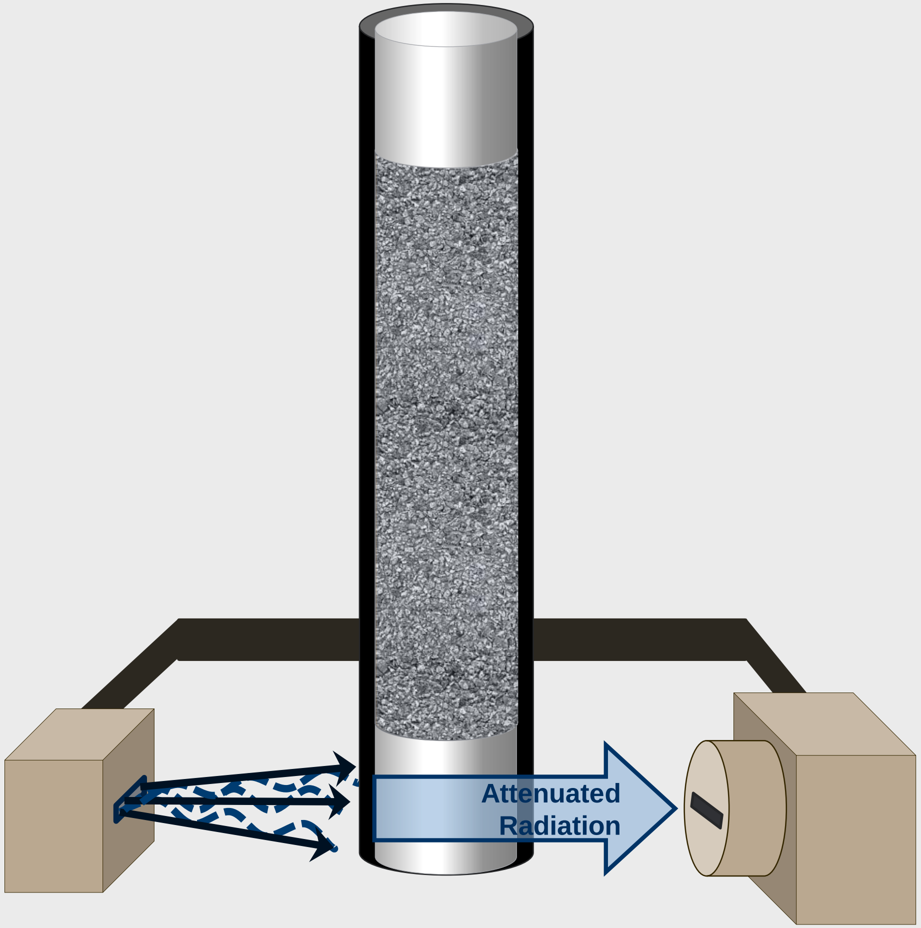
- Gamma usually exhibits higher energy than x-rays
  - Thus gamma requires longer scanning times to acquire sufficient counts to differentiate fluid (saturation) change
- Gamma usually requires ca. 2 - 10 mins per location (2 mm slice, 1.5” diameter core)
- X-ray usually requires 1-10 s per location (2 mm slice, 1.5” diameter core)

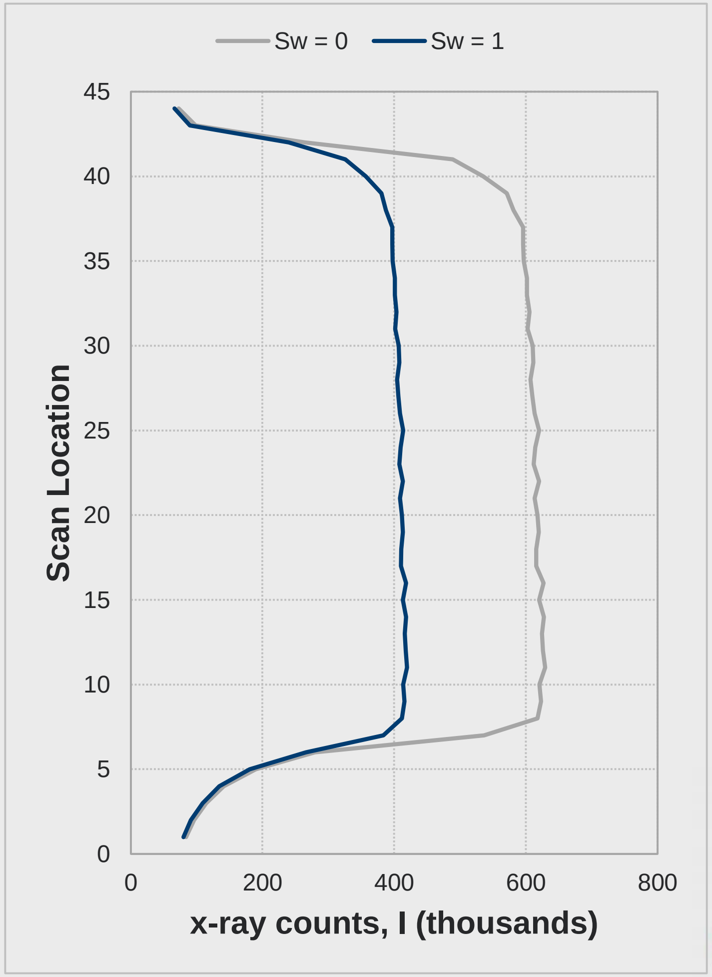
In situ saturation monitoring (ISSM)



- Method often requires one fluid phase to be "doped" (x-ray blocker added)
  - Iododecane
    - IFT reduced (ambient & temperature)
    - Problems at temperature
  - NaI
    - Light degradation
    - Temperature degradation
  - CsCl
    - Can be problematic for clay-rich samples
- "Doping" cannot be used during most chemical EOR processes

1D gamma / X-ray scanning





In situ saturation monitoring (ISSM)

- Saturation (for steady state relative permeability)
  - ISSM is the only recommended method
  - Alternatives (gravimetric and volumetric) incorporate large error
    - E.g.

oil production = 1505 – 1500 = 5 ml

- Saturation dependent upon viable calibration
  - Requires viable cleaning/displacement process
  - Assumes core unchanged
  - Assumes no significant movement of the scan location
    - Heterogeneities can cause significant error with sub-millimetre shifts

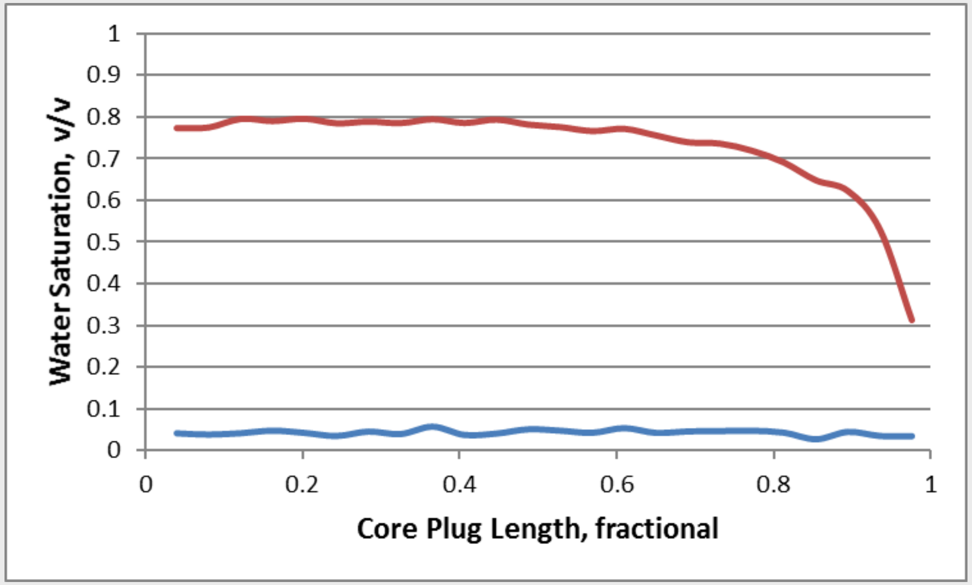
In situ saturation monitoring (ISSM)

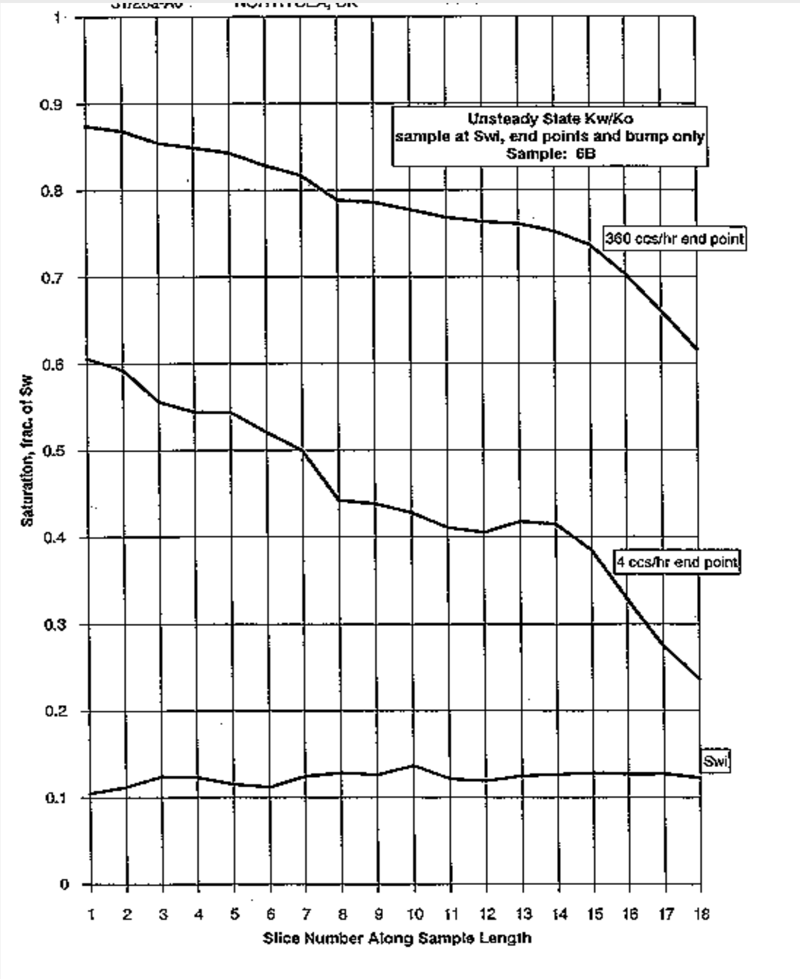
- Recommend saturation verification via some second method, e.g.
  - Dean-Stark inadvisable due to positional shift
  - Karl Fischer
    - Must ensure all water is removed
    - Possible errors for high water content
    - Possible errors for high clay content
  - tracer injection
  - dispersion analysis

Sample must be homogeneous

In situ saturation monitoring (ISSM)

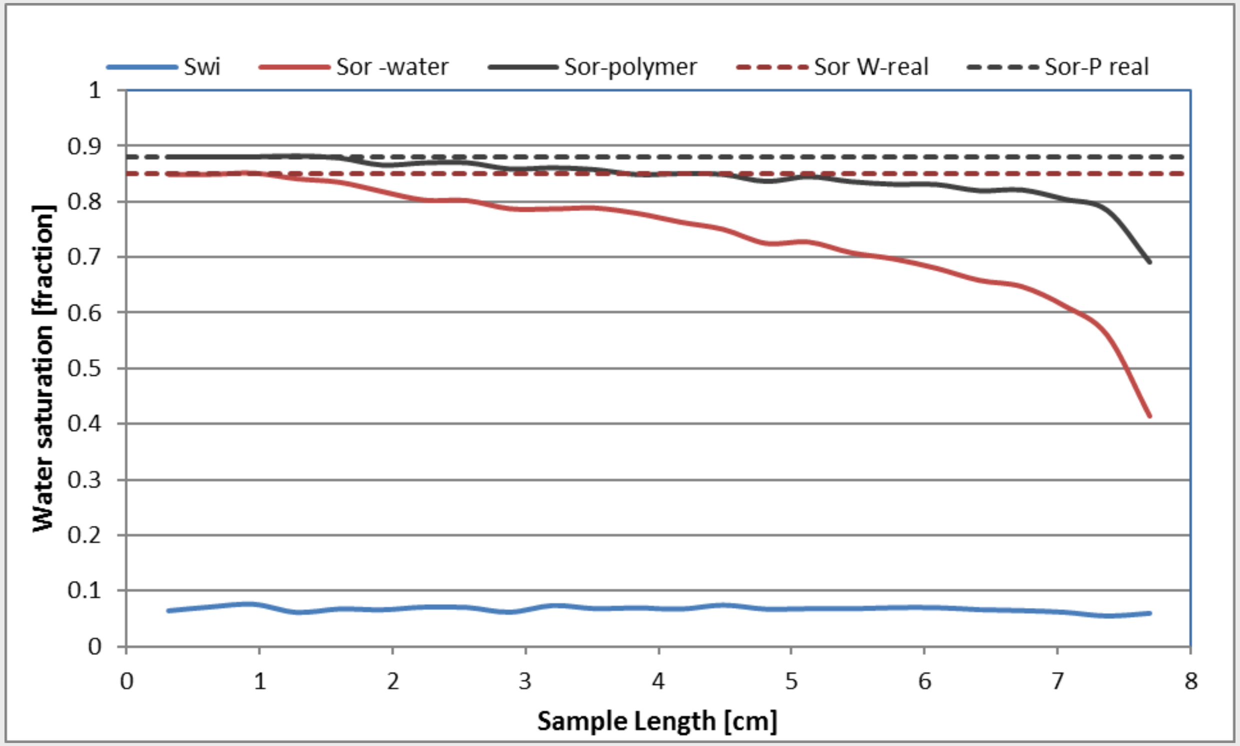
ISSM clearly shows capillary effects





In situ saturation monitoring (ISSM)

ISSM can show potential errors due to lab artefacts



Lab Average Sw

Waterflood-Sor = 0.72
EOR-Sor = 0.83
EOR potential = 11 s.u.

More realistic Sw

Waterflood Sor = 0.83
EOR-Sor = 0.87
EOR potential = 4 s.u.

Conclusions

- X-ray (or gamma) and x-ray computer tomography has been used for many years and is a verified imaging method that can be used for:
  - Reservoir characterisation, goniometry, fracture analysis, sample assessment and evaluation, sample selection, digital rock properties, saturation determination, etc.
- However, caution must be taken for the assumption that saturation can be obtained from x-rays alone
- Due to doping requirements, it is probably not viable for chemical EOR, except for very elongated scanning times