SCA 2017 – Vienna, Austria

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

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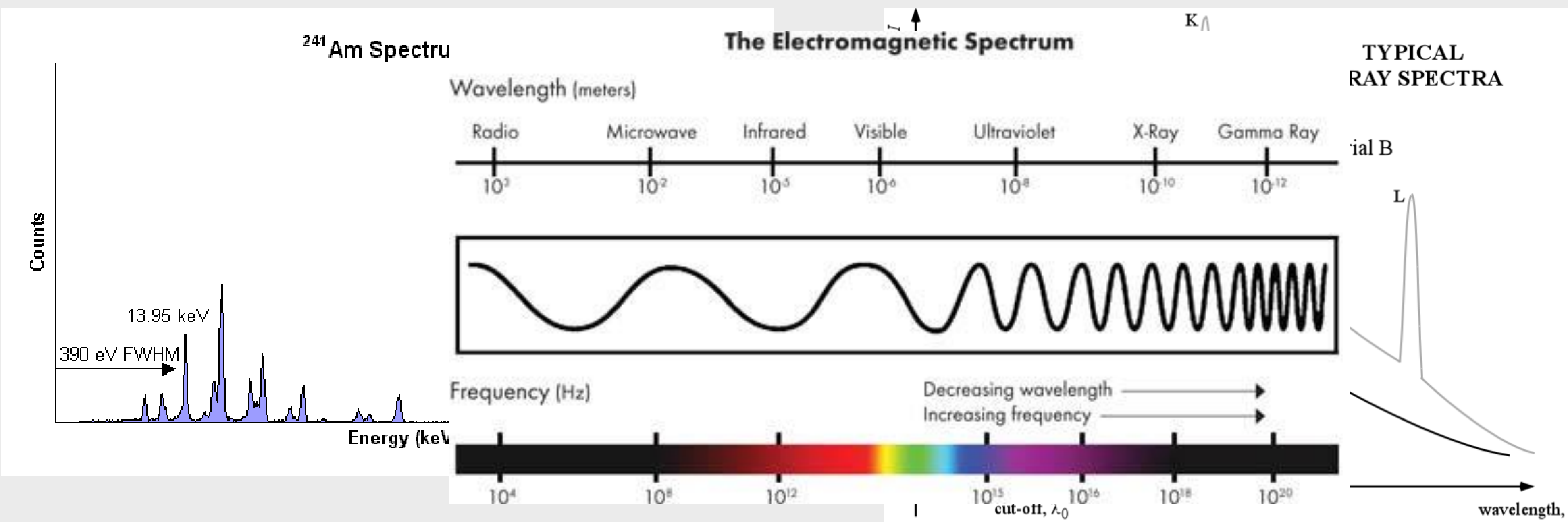
for a safer world

1D to 3D Imaging Methods

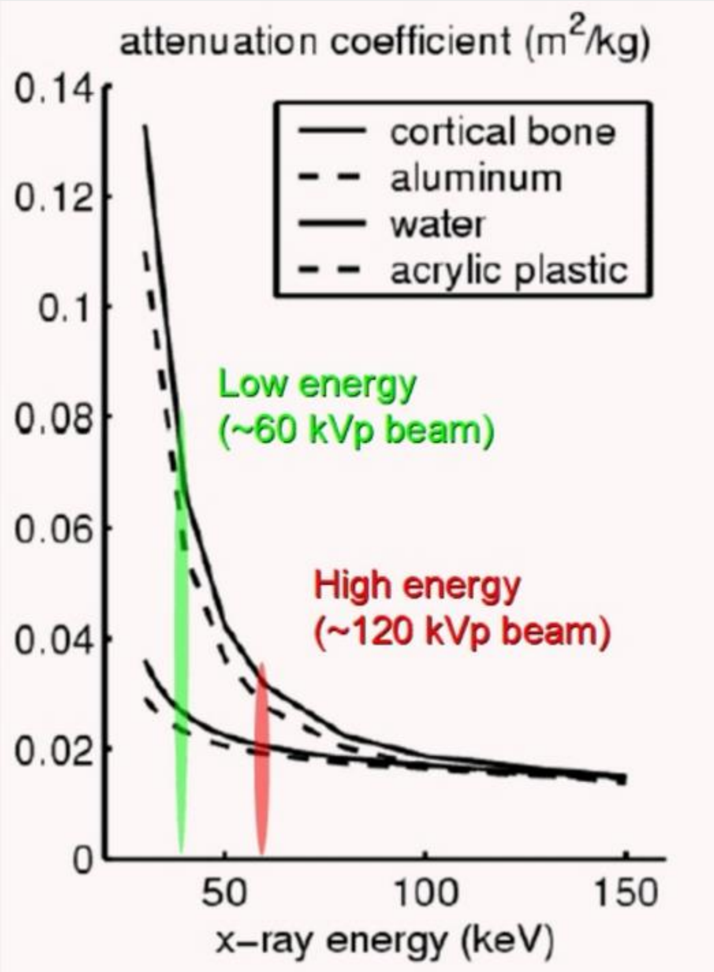
- Gamma ray, x-ray and CT
  - Gamma vs. x-ray
  - Gamma log
  - CT
    - Note regarding grey-scale images
    - Uses: description, analysis, assessment
- Beer-Lambert Law
  - 1D + time
    - Saturation determination
    - Considerations

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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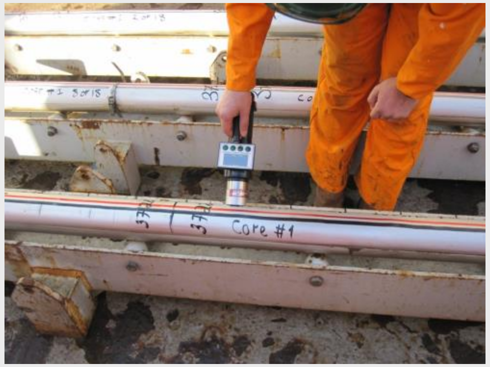
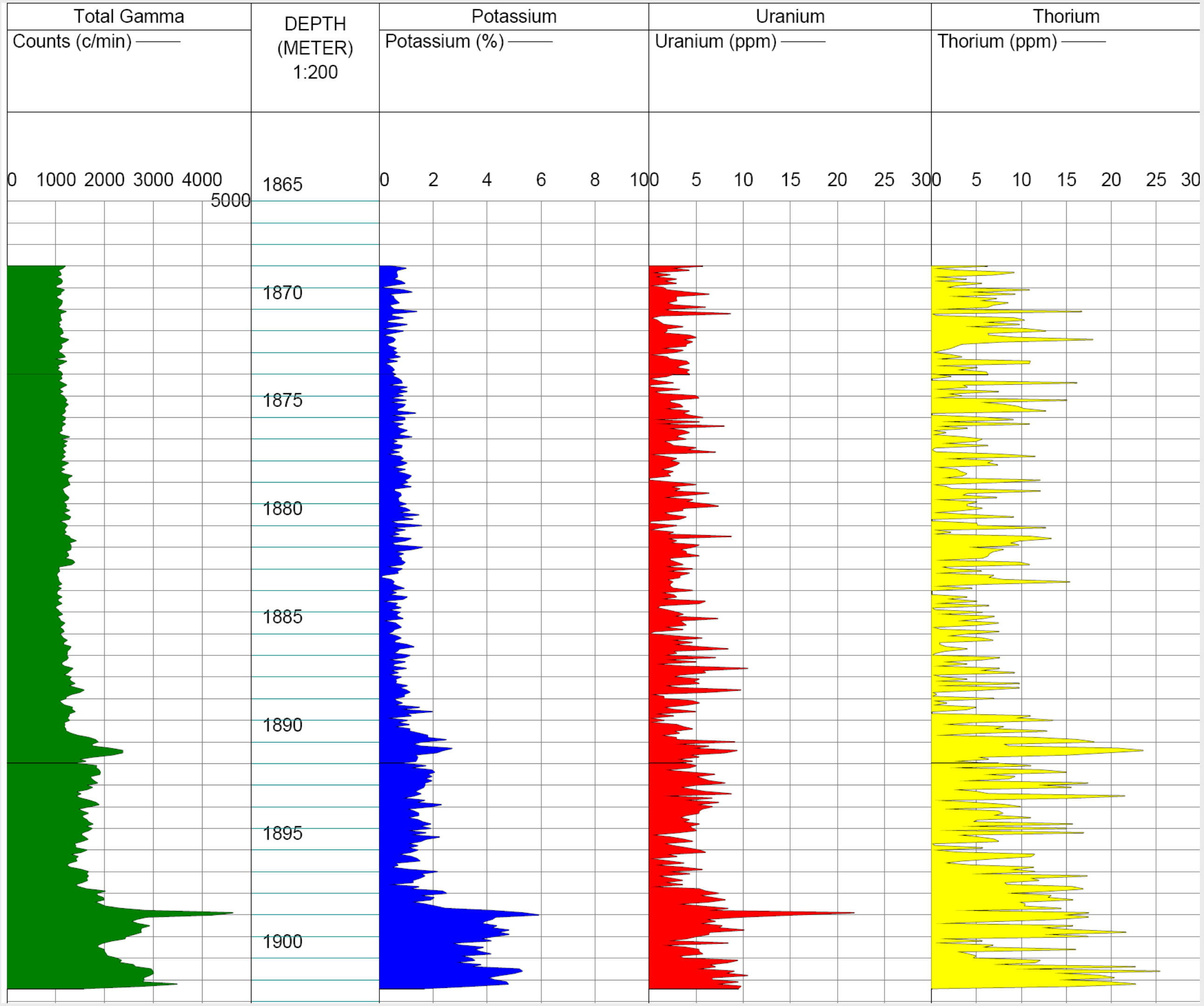
Core Gamma Ray Logging

- 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

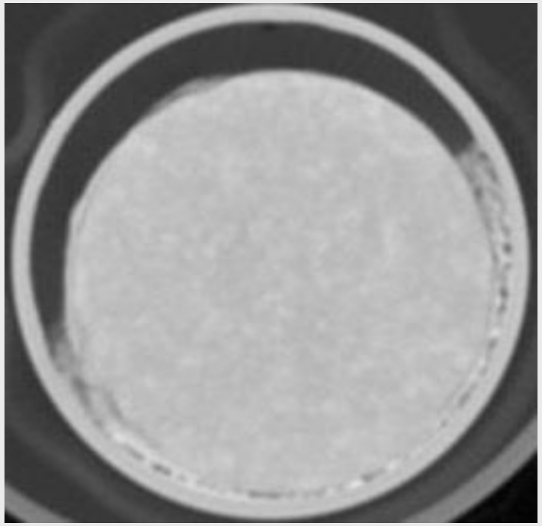
- Hounsfield Unit = measures radiodensity
  - function of attenuation coefficients

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

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

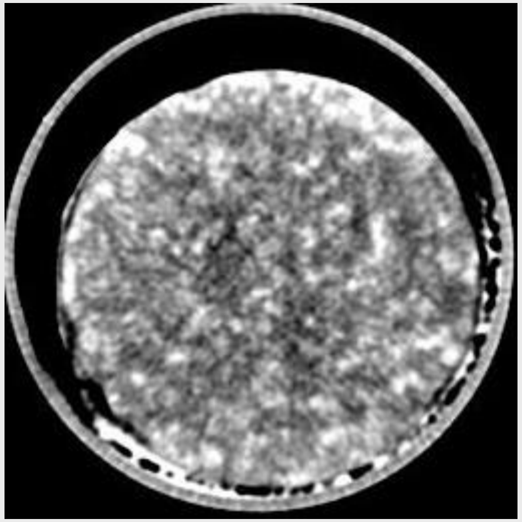
WL(or WC) = Centre HU setting
WW = Width HU Setting

Standard CT setting
WC-1000, WW-4096



Range = -1048 to 3048

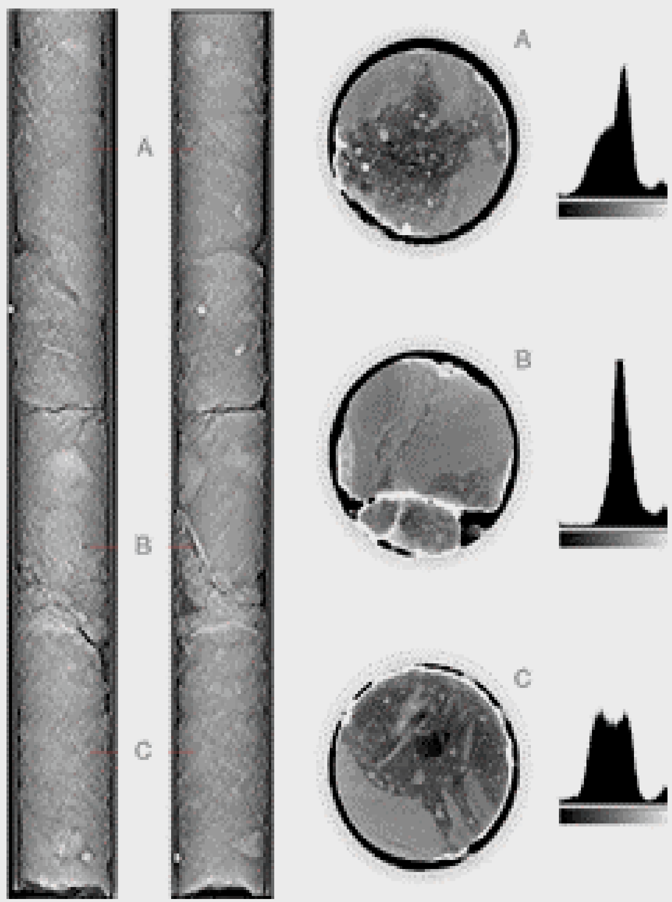
Core setting
WC-2000, WW-400

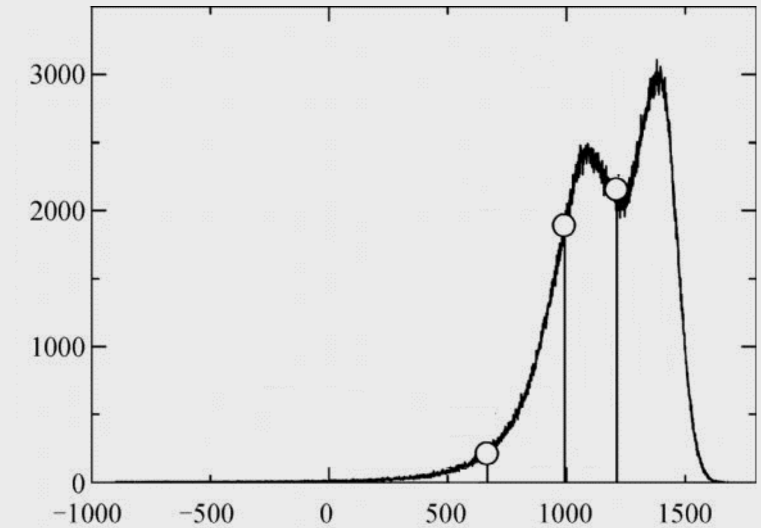


Range = 1800 to 2200

CT scanning – grey-scale image settings

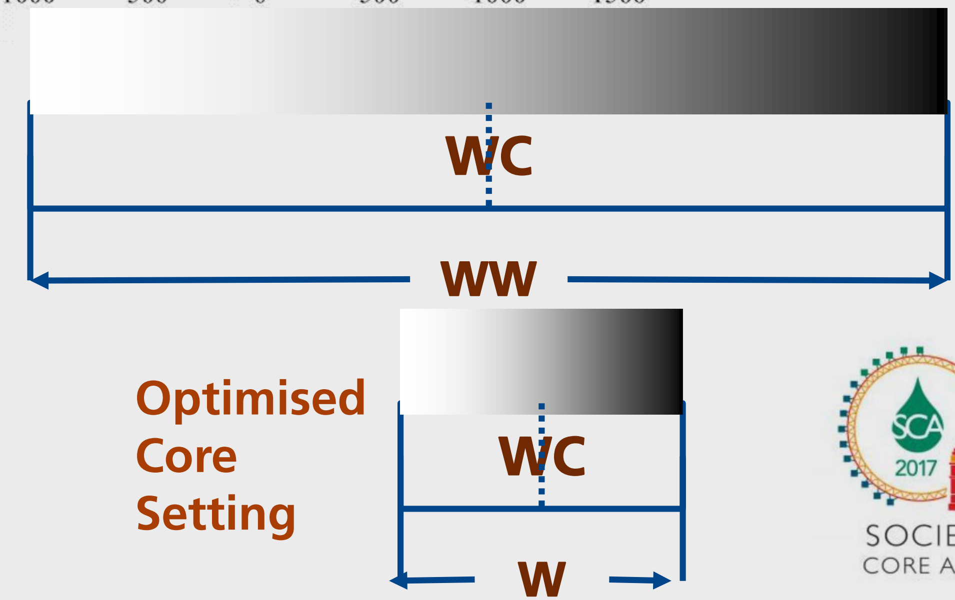
Different density profiles will require different HU image settings





Standard Equipment Setting

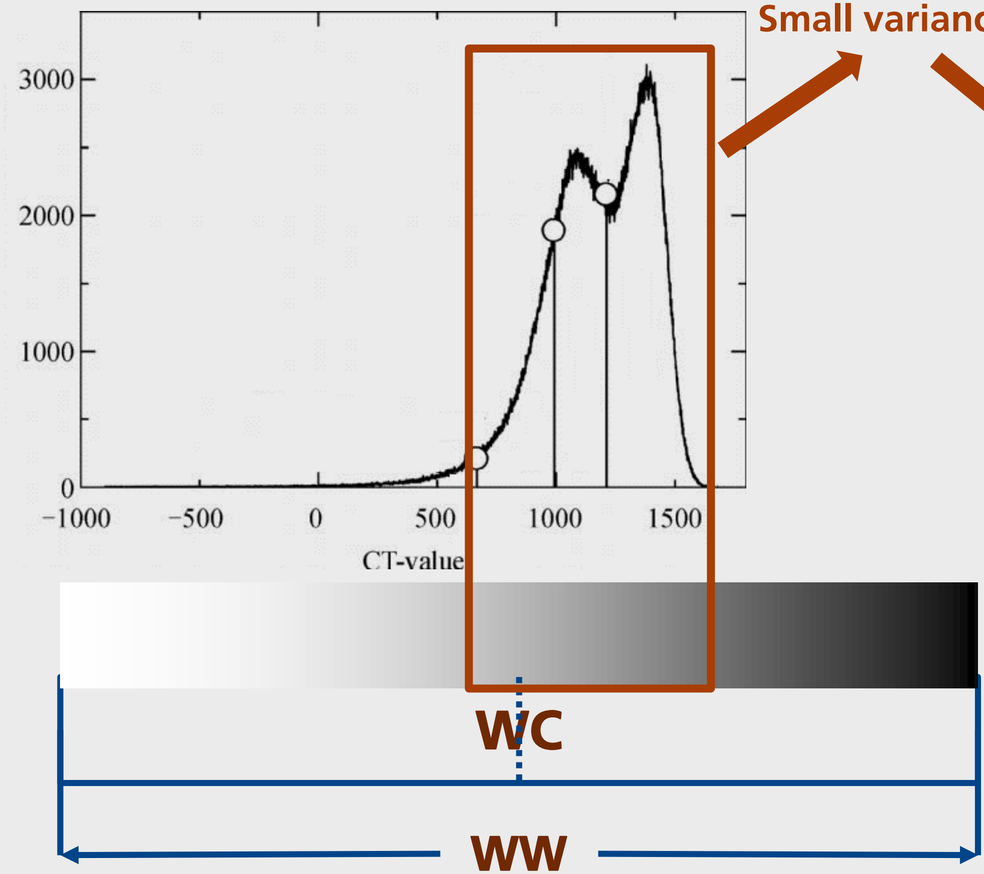
Optimised Core Setting



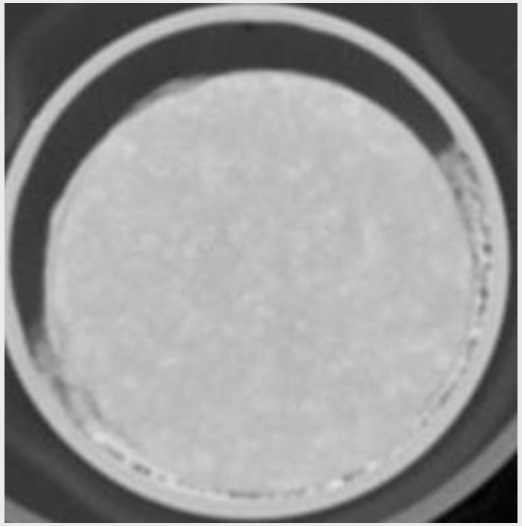
CT scanning – grey-scale image settings

Standard CT equipment setting

WC = 1000
WW = 4096



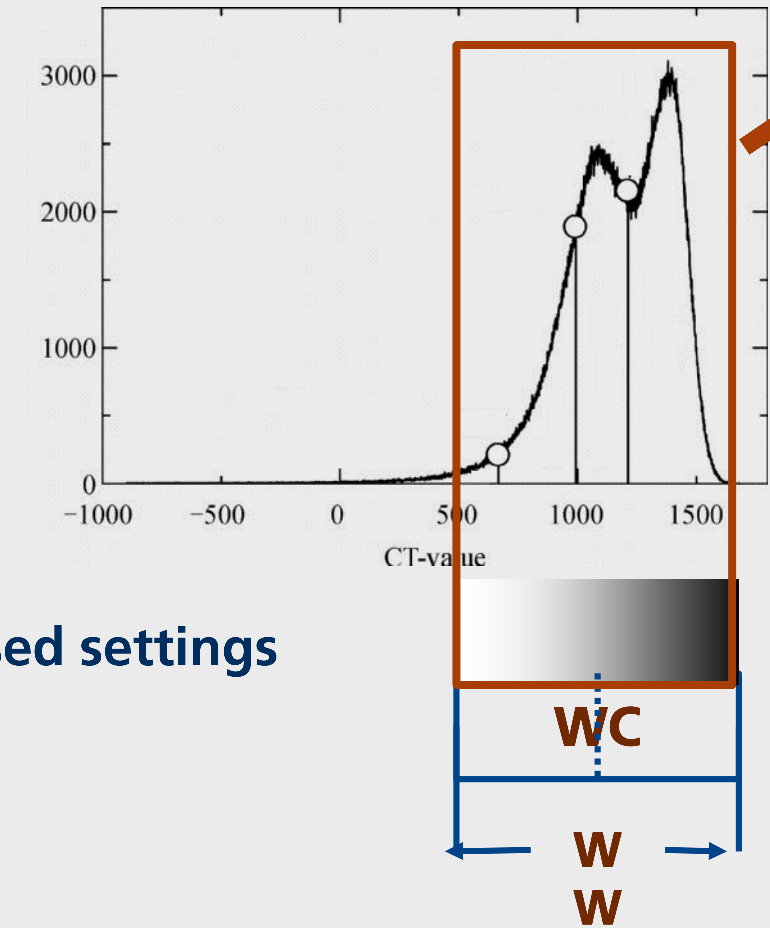
Core density in the middle of the grey-scale
Small variance in observed image

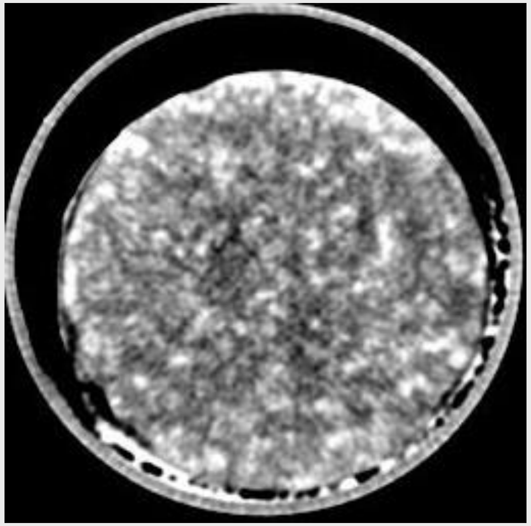


CT scanning – grey-scale image settings

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

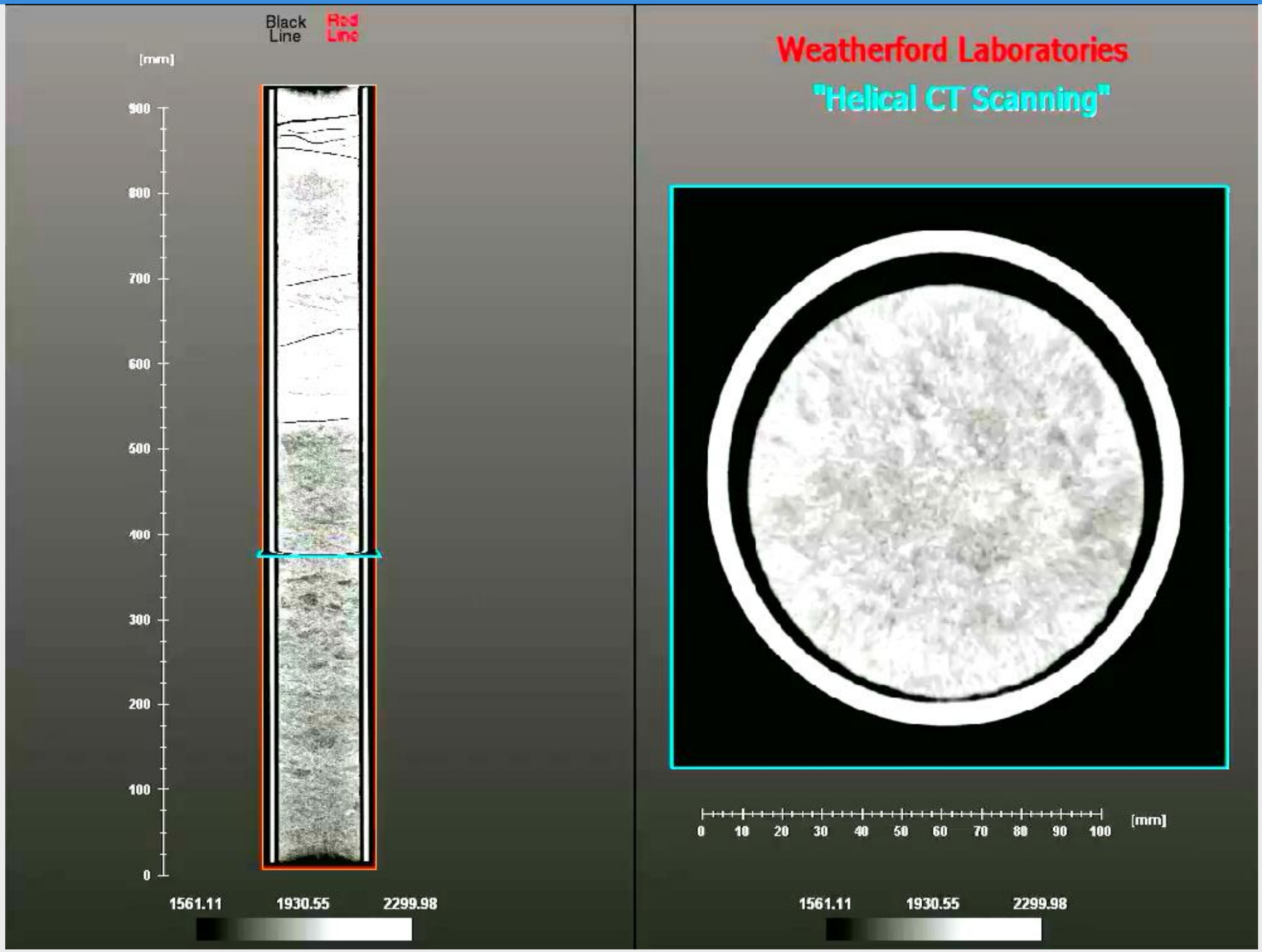
Grey-scale optimised from lowest to highest density
Variance in observed image – white to black



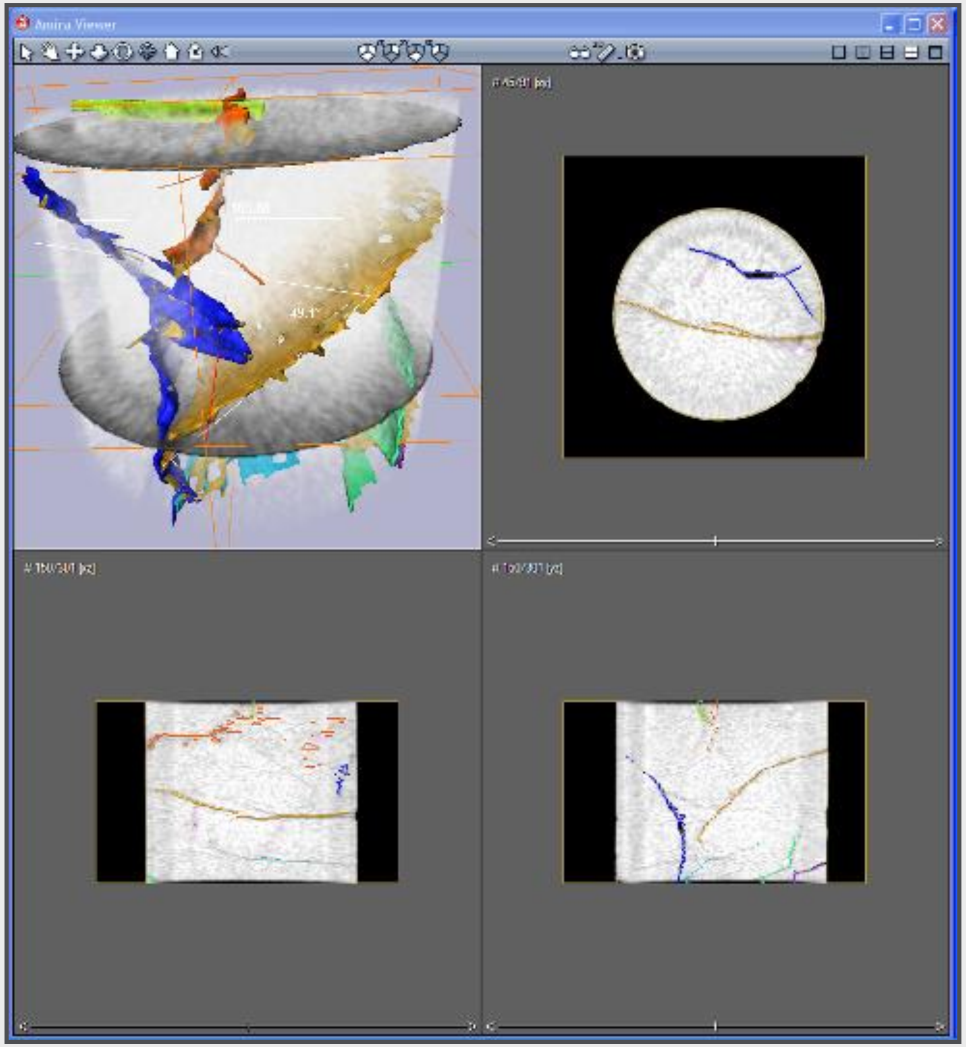


Optimised settings

Helical CT scan – 3D

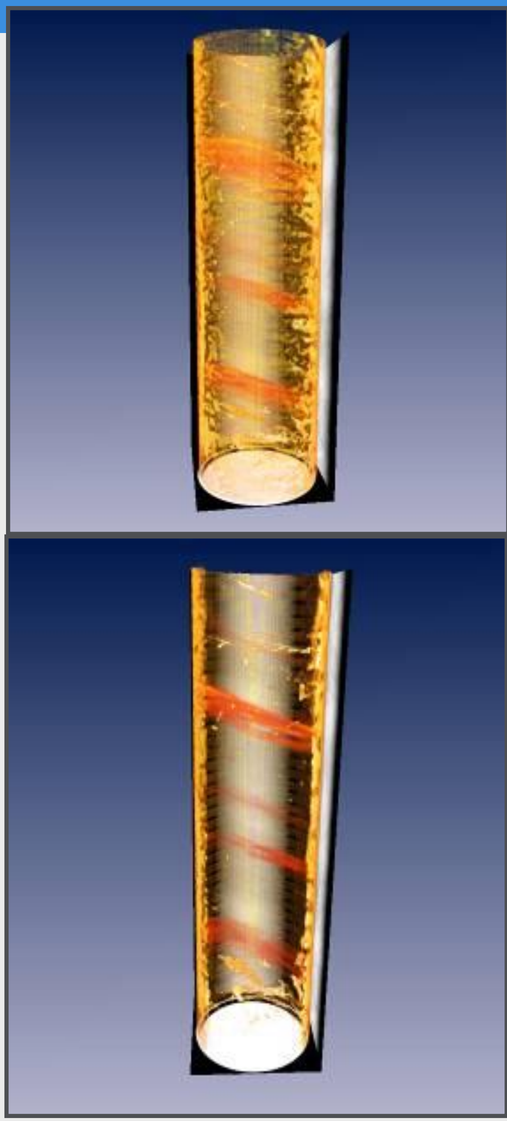


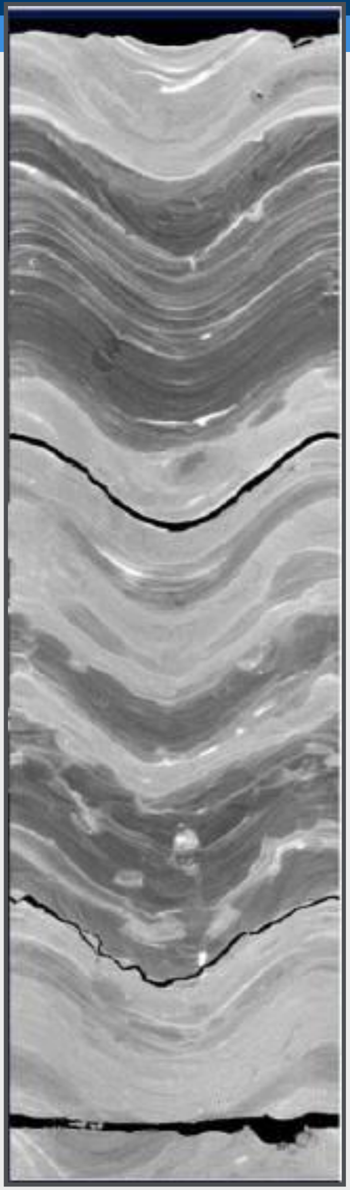
Helical CT scan – 3D analysis

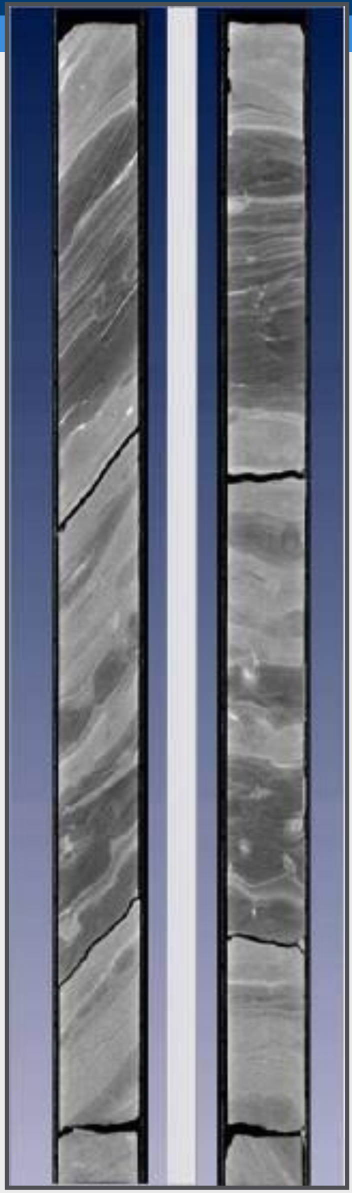


- 3D scans allow various analytics
- Feature Identification Options
- Each feature is extracted, named, and analyzed separately. For each feature, you can specify name, color, and visibility options.

Helical CT scan – 3D analysis

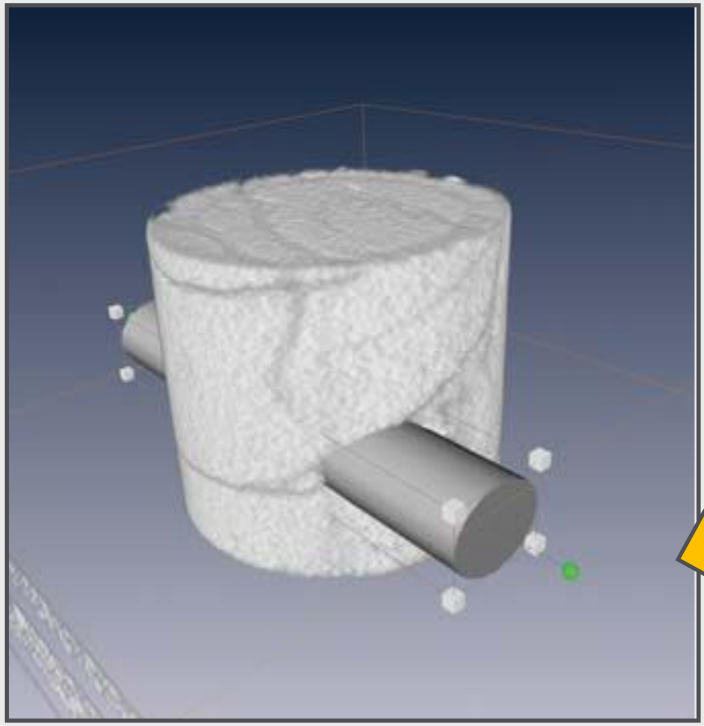




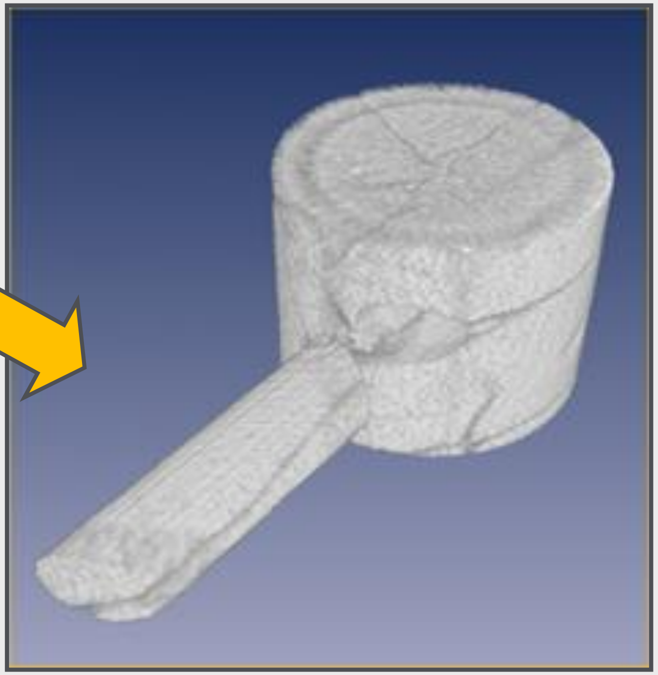


- Orientation
- Dip
- Strike
- Image log correlation

Helical CT scan – 3D analysis



- Virtual Plug Extraction
  - Assess plug viability before acquiring



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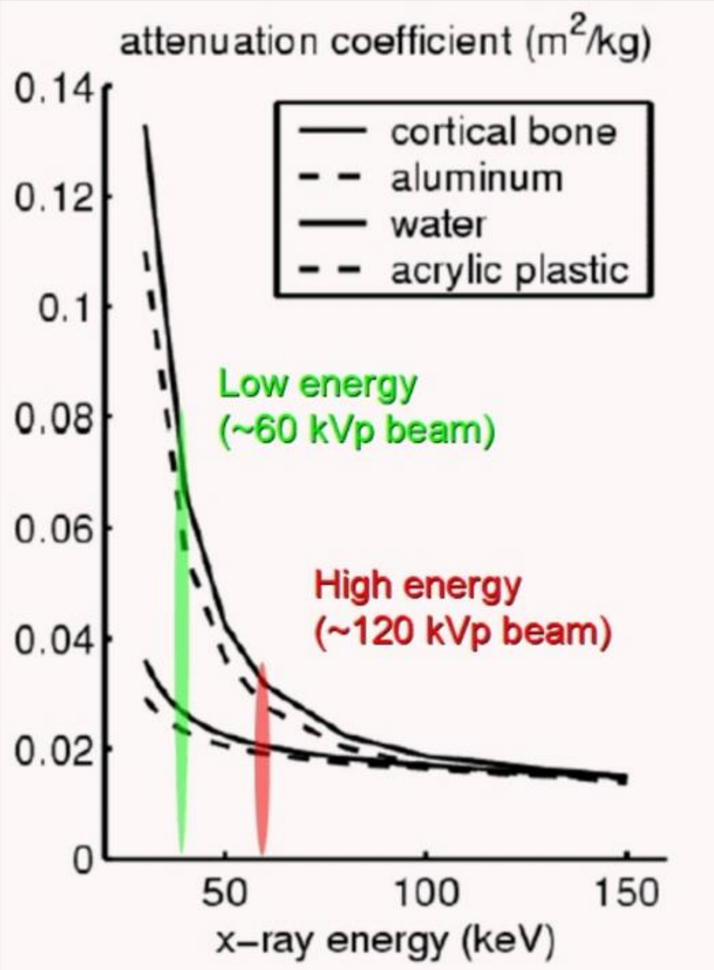
  - 1D + time (in situ saturation monitoring [ISSM])
    - Saturation determination
    - Considerations

Attenuation – Beer-Lambert Law



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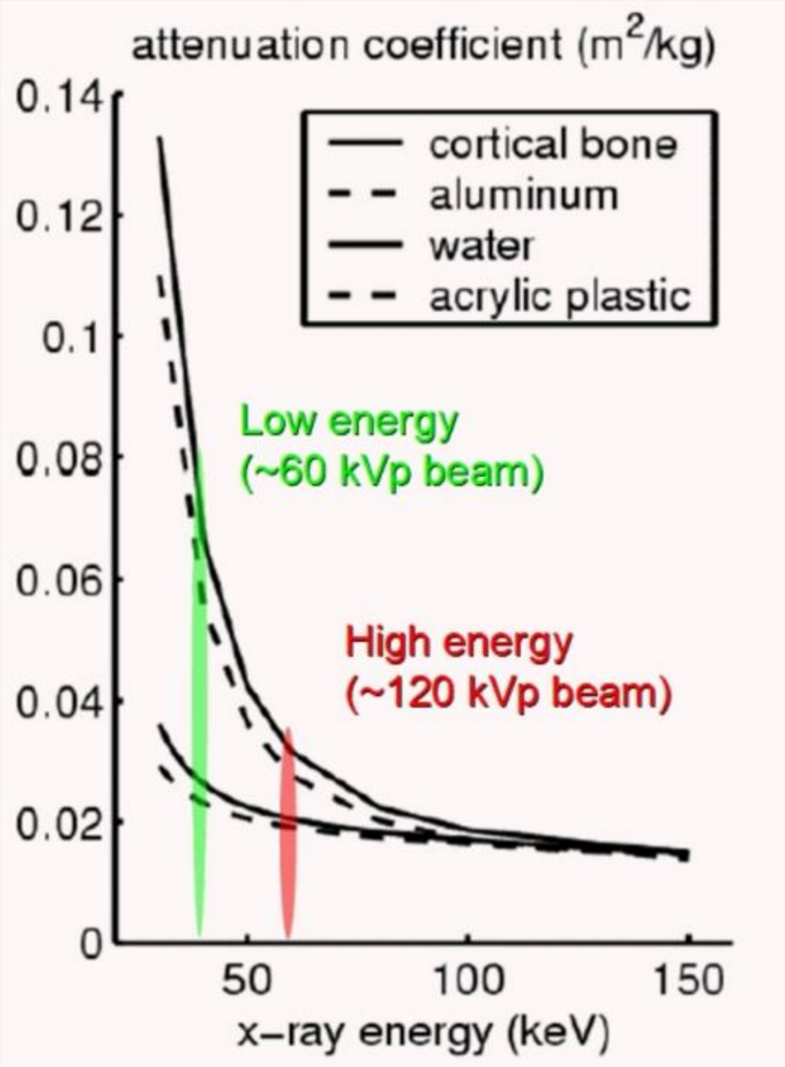
In situ saturation monitoring (ISSM)

- 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:

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

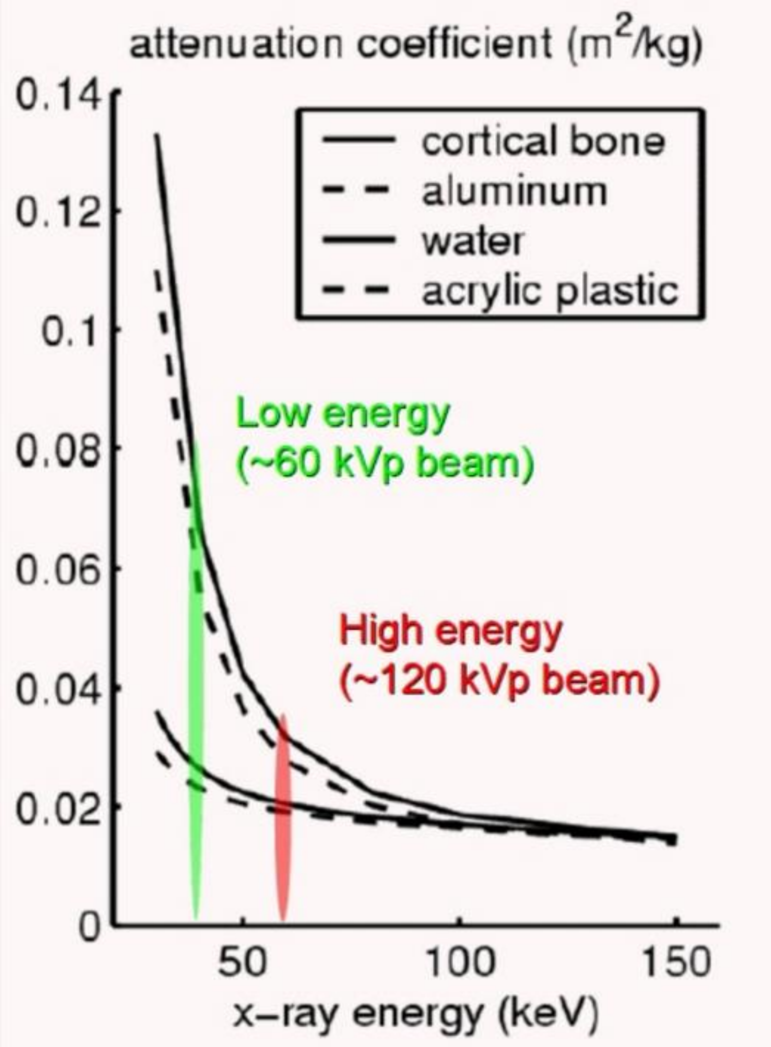
    - I_{Sw} is Sw=1, I_{So} is Sw = 0

In situ saturation monitoring (ISSM)



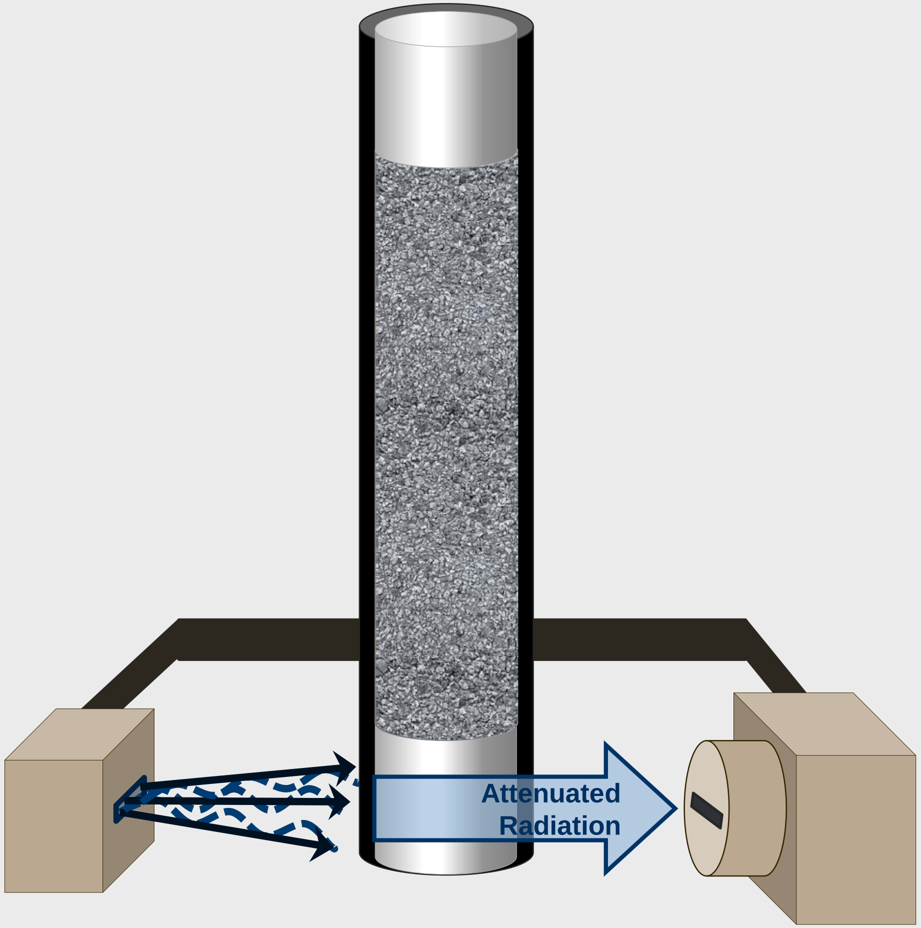
- Gamma usually exhibits higher energy than x-rays
  - Thus gamma requires longer scanning times to acquire sufficient counts to differentiate fluid (saturation) change
- Gamma usually requires ca. 2 - 10 mins per location (2 mm slice, 1.5” diameter core)
- X-ray usually requires 1-10 s per location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

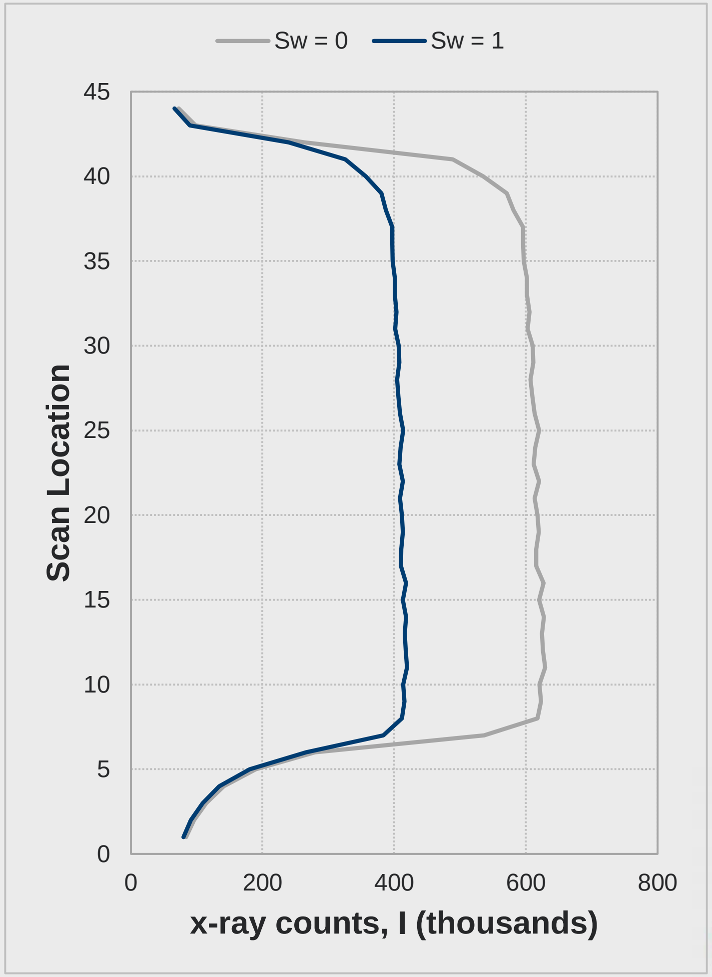
In situ saturation monitoring (ISSM)



- 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

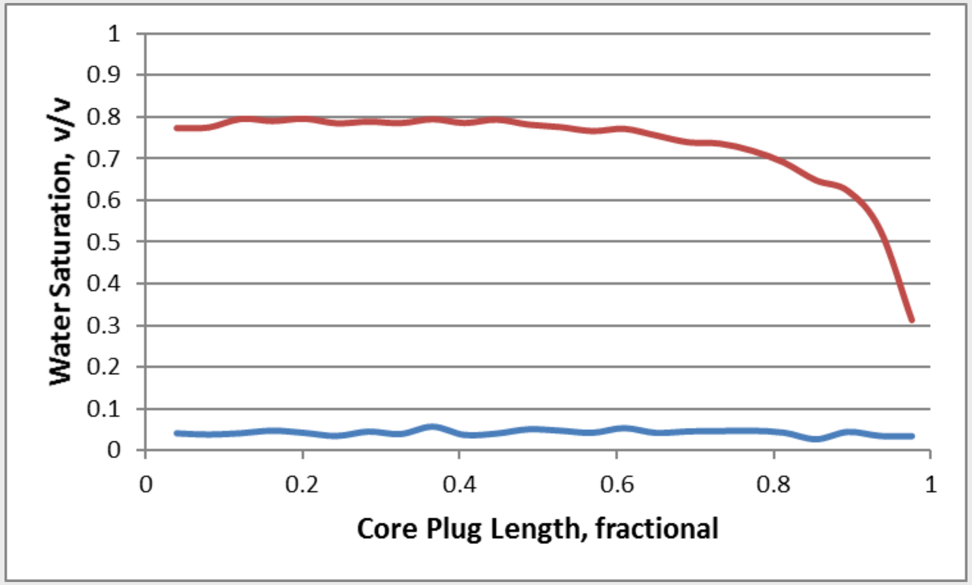
- Saturation dependent upon viable calibration
  - Requires viable cleaning/displacement process
  - Assumes core unchanged
  - Assumes no significant movement of the scan location
    - Heterogeneities can cause significant error with sub-millimetre shifts

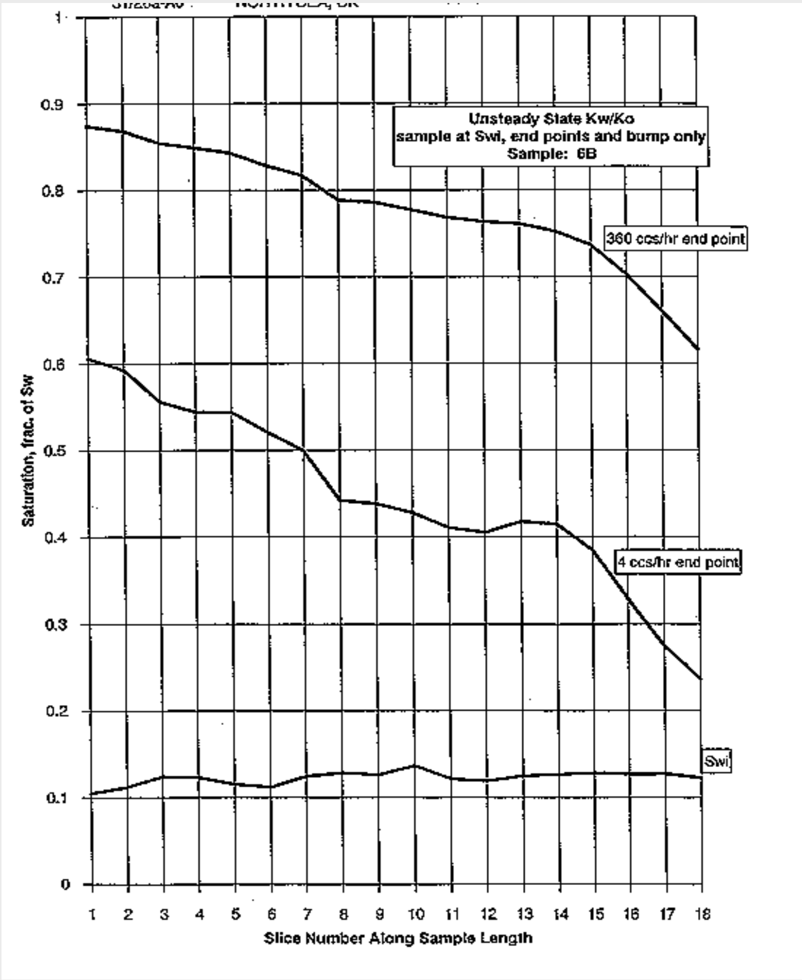
In situ saturation monitoring (ISSM)

- 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

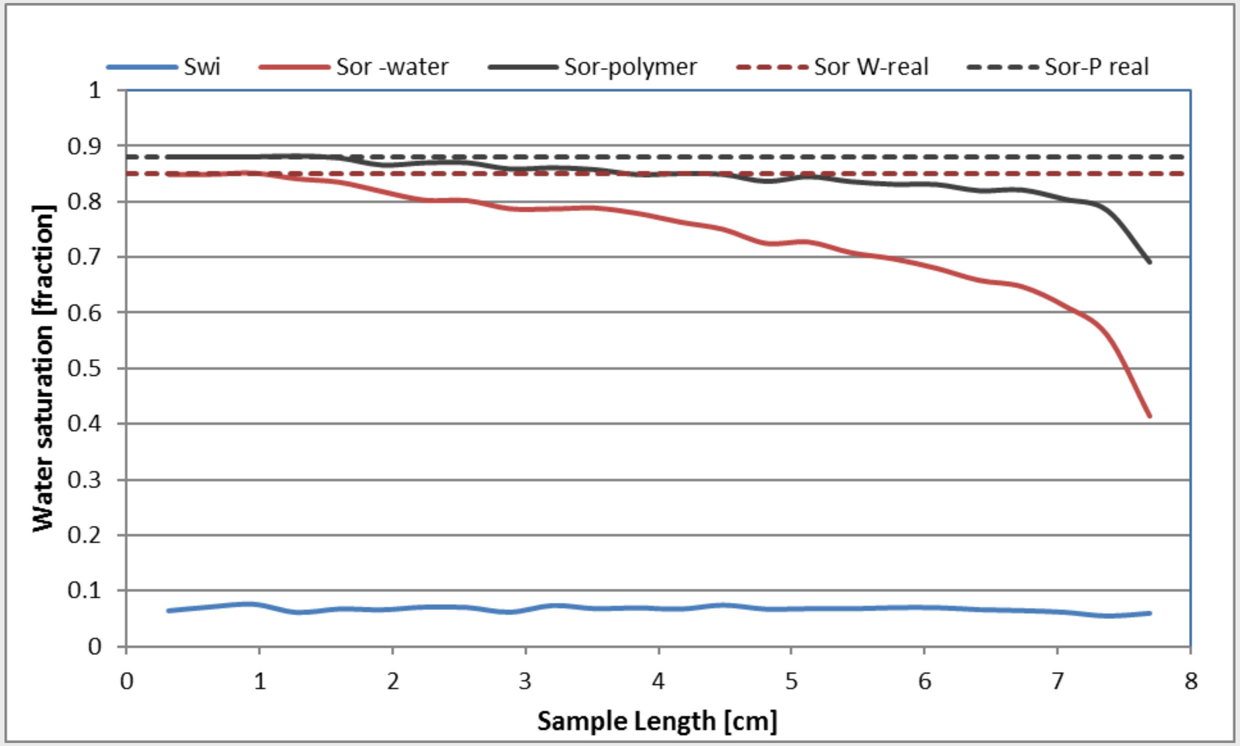
Sample must be homogeneous

ISSM clearly shows capillary effects





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