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Using downhole probing for real-time grade estimation for uranium exploration and mining

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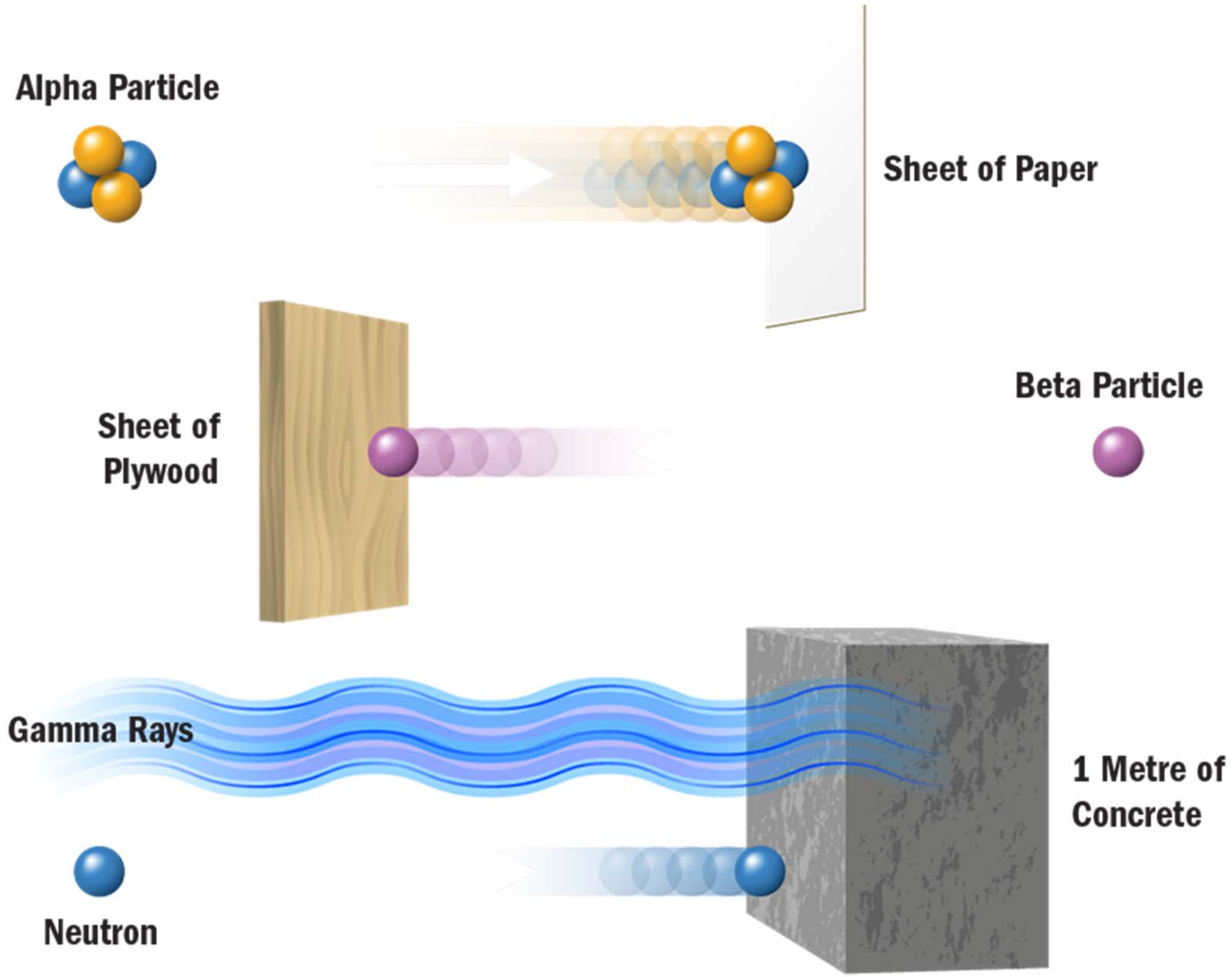
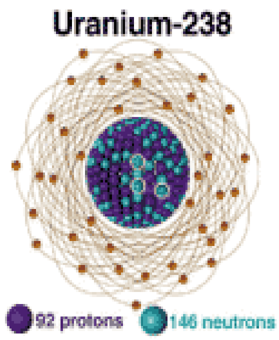
Radiation 101

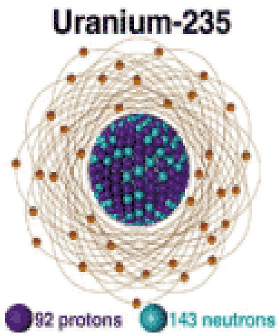


Uranium Isotopes

- There are over 26 different isotopes of uranium! Most of these have half lives of several nano or micro seconds!
- Only two of these occur naturally
- U^{238} – 99.28% found worldwide.
- U^{235} – 0.71% found in one deposit in Gabon (Africa).



extra neutrons - heavier



lighter and more active

- U^{238} is fissionable (i.e. relatively stable). Cannot sustain a chain reaction on its own.
- U^{235} is fissile and can self sustain a chain reaction.
- The uranium isotope used as fuel in Nuclear Reactors is U^{235}

Simplified U238 Decay Series

U^{238} decays to Th^{234} by emitting 2 alpha particles

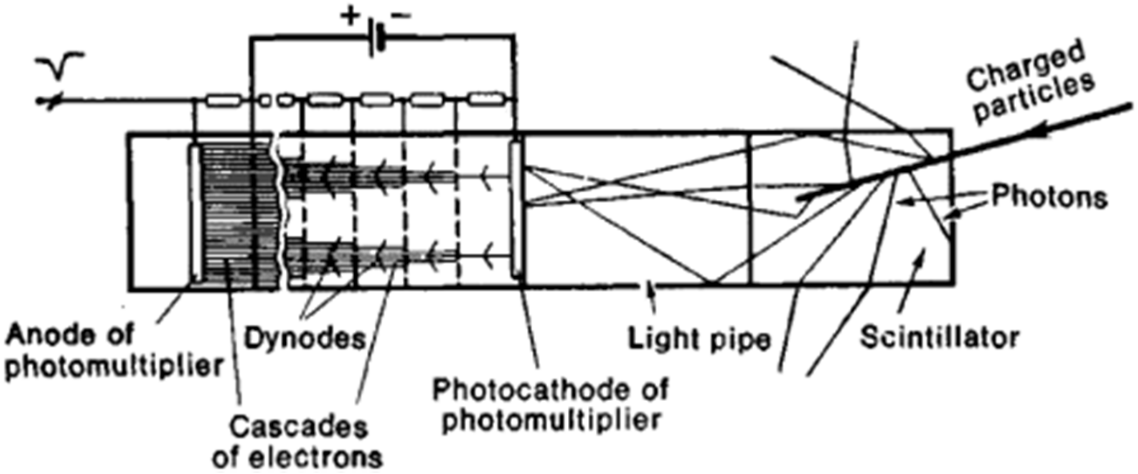
Th^{234} decays to Pa^{234} by emitting a beta particle

First significant gamma emission

Isotope	Emission	Half-life
U^{238}	α	4.507 $\times 10^{9}$ years
Th^{234}	β	24.1 days
Pa^{234}	β	1.18 min
U^{234}	α	2.48 $\times 10^{5}$ years
Th^{230}	α	7.52 $\times 10^{4}$ years
Ra^{226}	α	1600 years
Rn^{222}	α	3.825 days
Po^{218}	α	3.05 min
Pb^{214}	$\gamma\beta$	26.8 min
Bi^{214}	$\gamma\beta$	19.7 min
Po^{214}	α	1.58 $\times 10^{-4}$ secs
Pb^{210}	β	22.3 years
Bi^{210}	β	5.02 days
Po^{210}	α	1.384 days
Pb^{206}	stable	

Detectors- Scintillometer

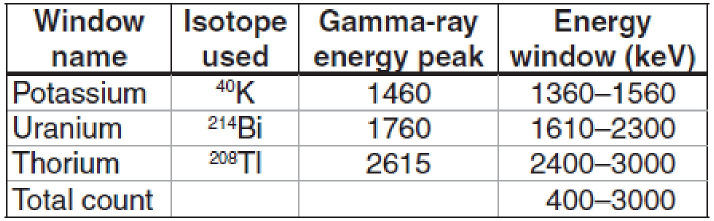
- Most radiometric tools detect gamma radiation using a crystal (either Lead Iodide, Bismuth-germ-oxide or Brilliance)
- Laboratory grown crystal but each has its own imperfections and fractures (uniqueness).



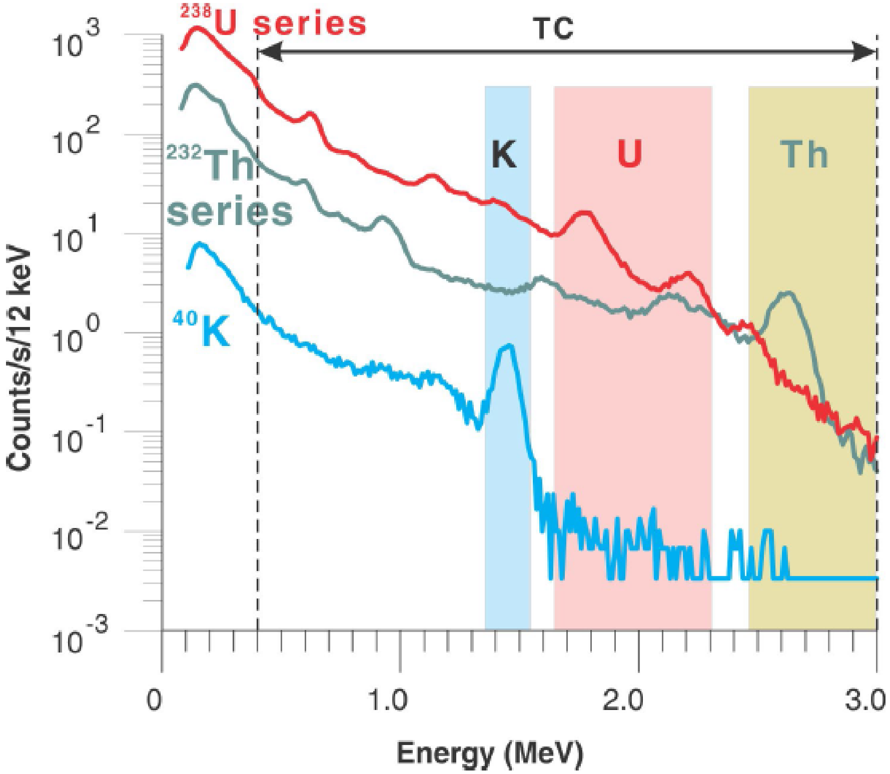
- Crystal size (volume) determines sensitivity
- Shields can be used to reduce sensitivity
- Temperature sensitive

Detectors- Spectrometer

- Uses crystals as per scintillometer
- **Key Benefits**
  - The estimation of eU
    - Is far more accurate estimation of concentration allowing for the contribution of Th and K
    - Is less prone to user errors due to the above assumption
- Better lithological discrimination
- Possible identification of potassium alteration

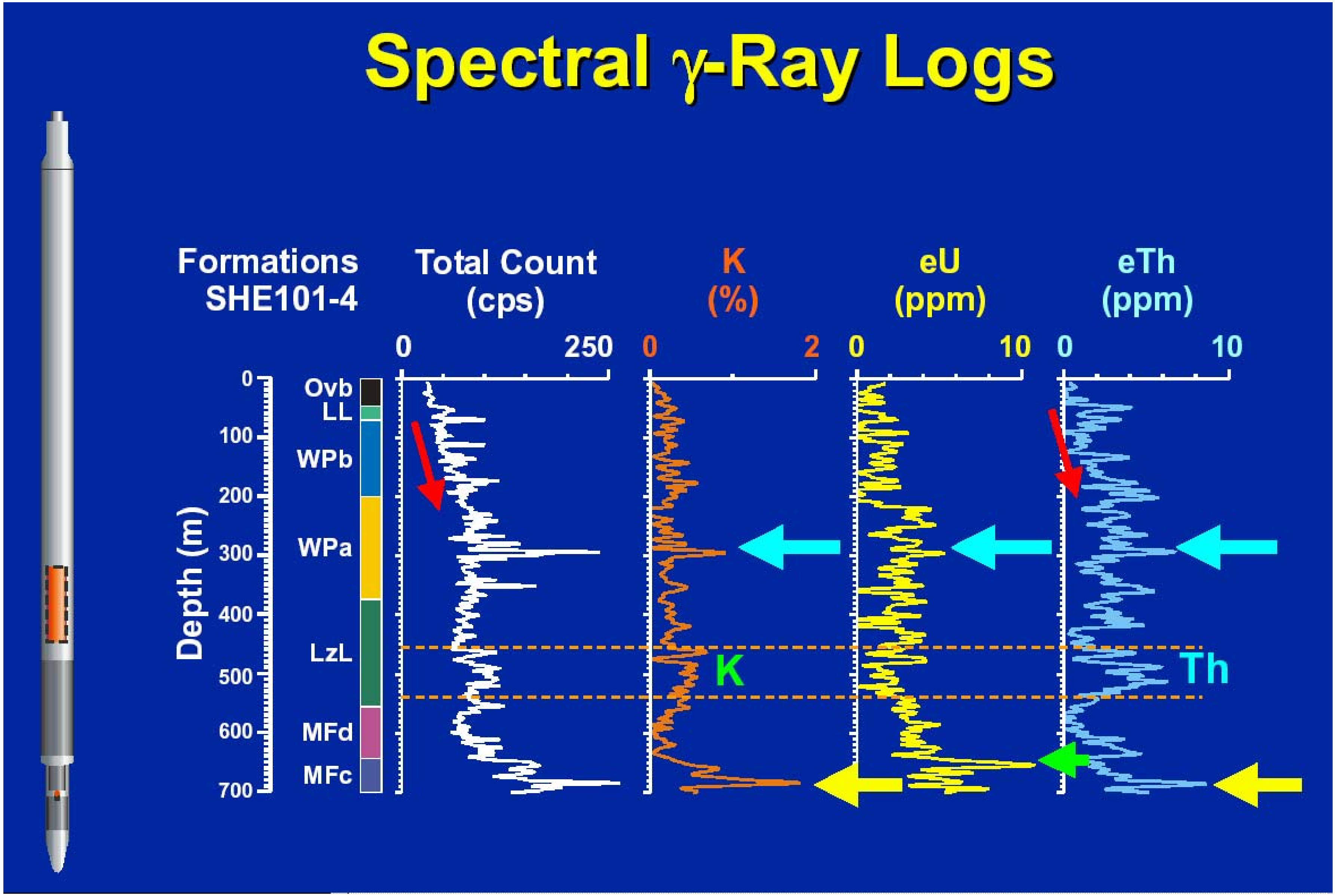


Window name	Isotope used	Gamma-ray energy peak	Energy window (keV)
Potassium	^{40}K	1460	1360–1560
Uranium	^{214}Bi	1760	1610–2300
Thorium	^{208}Tl	2615	2400–3000
Total count			400–3000



From Mwenifumbo and Mwenifumbo , 2013

Detectors- Spectrometers



Detectors - (Geiger Muller)

- Gaseous ionization detector
- Detects ionizing radiation from gamma, x-rays, alpha and beta particles and neutrons
- Ionizing radiation causes a particle avalanche towards central anode wire held at ~500V
- Pulse widths on the order of 75µs
- Good for high grade deposits
- Very Robust

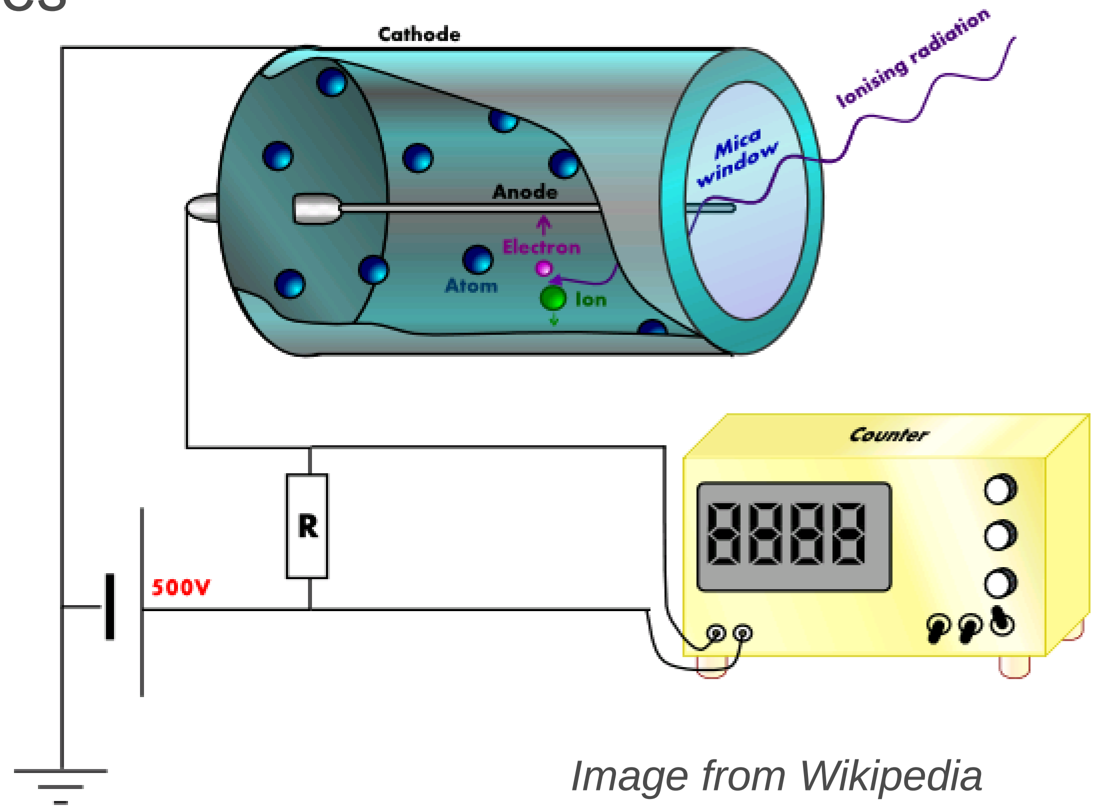


Image from Wikipedia

Gamma Lithology logging

Clays	
Kaolinite	80 – 130
Chlorite	180 – 250
Illite	250 – 300
Montmorillonite	150 – 200

Micas	
Muscovite	~ 270
Biotite	~ 275
Most Others	0

No Response
Silicates
Carbonates
Oxidates
Phosphates
Coals
Sulphides

Evaporites	
Sylvite	500+
Carnalite	~220
Langbeinite	~290
Polyhalite	~200
Kainite	~245
Others	0

Feldspars	
Alkali	~ 220
Plagioclase	0

** Units are in API defined such that a concrete block in Houston = 200 API, twice the radioactivity of a typical shale

All values supplied by Schlumberger

Using Gamma rays to estimate Uranium

Isotope	Emission	Half-life
U^{238}	α	4.507×10^{9} years
Th^{234}	β	24.1 days
Pa^{234}	β	1.18 min
U^{234}	α	2.48×10^{5} years
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Pb^{206}	stable	

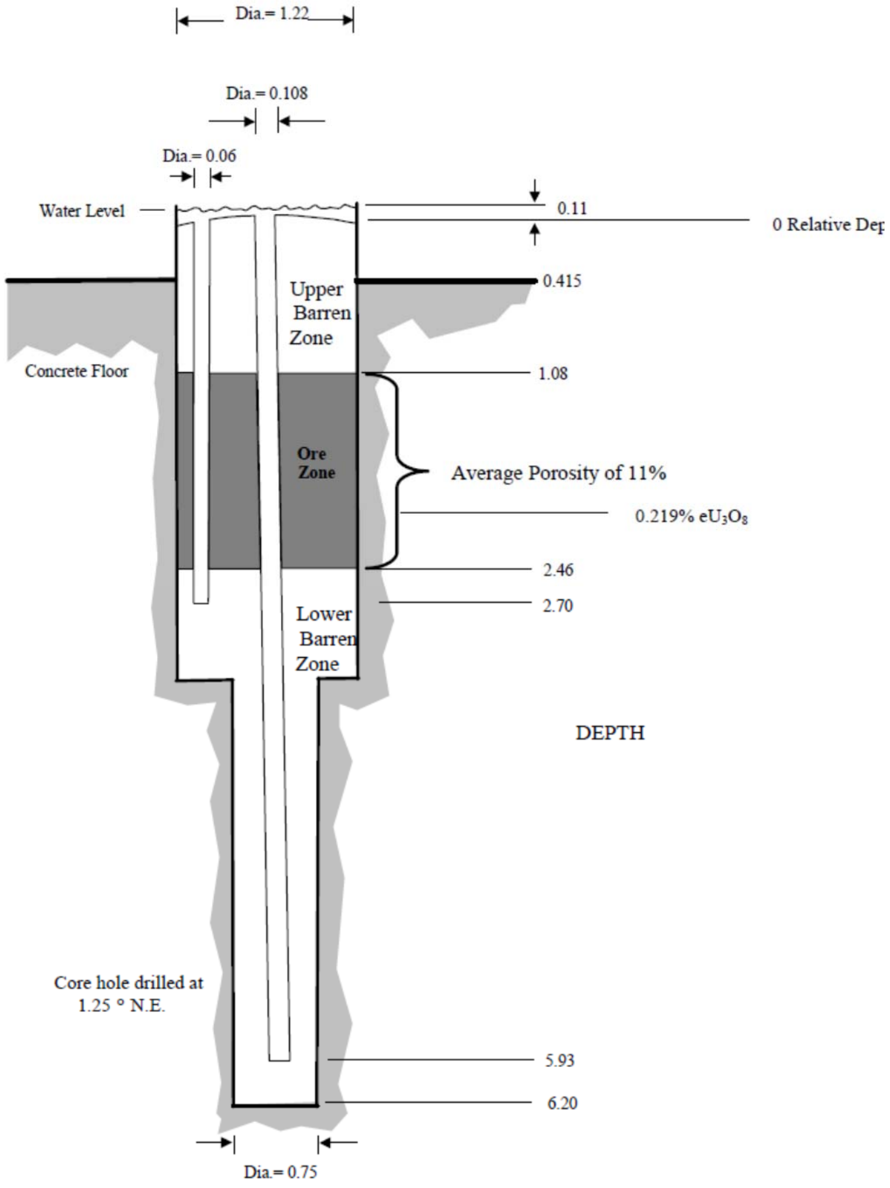
When the decay chain is fully established (***in Equilibrium***) we can measure the number of Pb^{214} atoms that are decaying to Bi^{214} and using a correction factor we can then calculate how much uranium is there.

$$\text{Counts}^{\text{Per Second}} \times \text{K-factor} = \text{eq } U_3O_8 \text{ ppm}$$

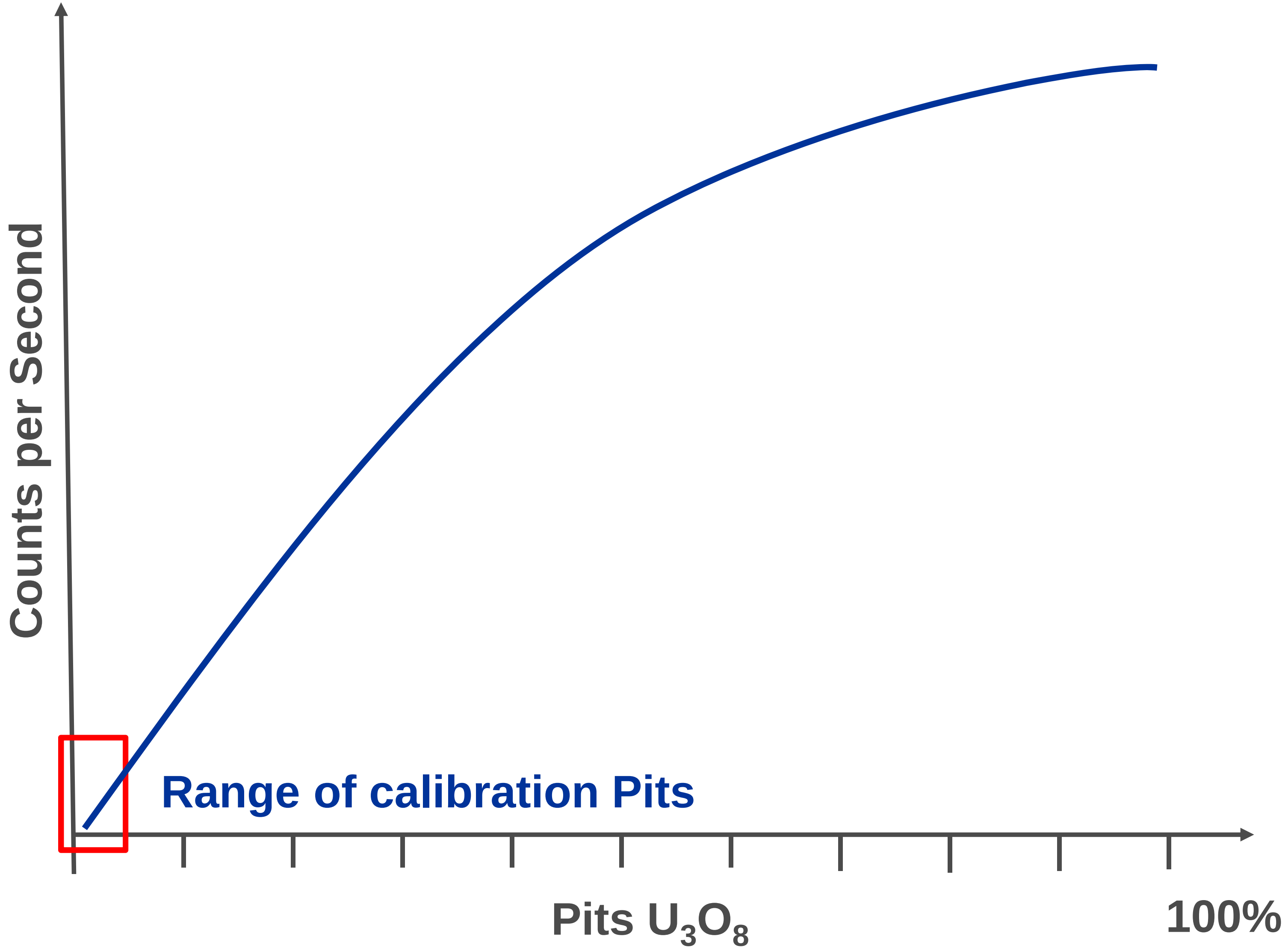
Grade Calculation-calibration

- Adelaide, South Australia
- Grand Junction, USA
- SRC, Saskatoon Canada
- South Africa
- Operating mines

- **Adelaide Facility**
  - AM1 0.219% eU_3O_8
  - AM2 0.920% eU_3O_8\
  - AM3 0.054% eU_3O_8
  - AM7 0.17% eU_3O_8
  - AM4 37 ppm eU_3O_8, 4.52%K, 70.3ppm ThO_2



Ideal Grade Calculation



Grade Calculation

$$\boxed{G = K \times F_m(r) \times F_z(r)\ \ x\, F_w(r)\, F_c(r) \times F_d(r)}$$

G = Grade

K = constant of calibration

F_m(r) = Moisture Factor to correct for differences in formation water (100 – % water in calibration model)/(100 – % water in formation),

F_z(r) = Z-effect Factor to correct for the presence of U itself, which is a function also of R,

F_w(r) = Water Factor for differences in the fluid between test-pit and field drillhole

F_c(r) = Casing Factor to correct for hole rod or casing material

F_d(r) = Dead-time Factor, also a function of r

r = count rate

From Dickson, 2012

K Factor

$$\boxed{K\ Factor = \frac{Dead\ Time\ corrected\ Count\ Rate}{Grade\ of\ Calibration\ Pit}}$$

Dead time correction(τ)

- **Dead-Time Refers to a probes counting inefficiencies**
  - Originated to describe the behaviour of Geiger Muller detectors which became insensitive for a brief period of time immediately after a cascading event (circa 1930's – 1940's)
  - In modern times the term has been extended to describe any losses of counts due to coincident counting (AKA - pulse pile up), detector / electronic inefficiencies, or in the case of analog probes pulse loss in the wire-line.

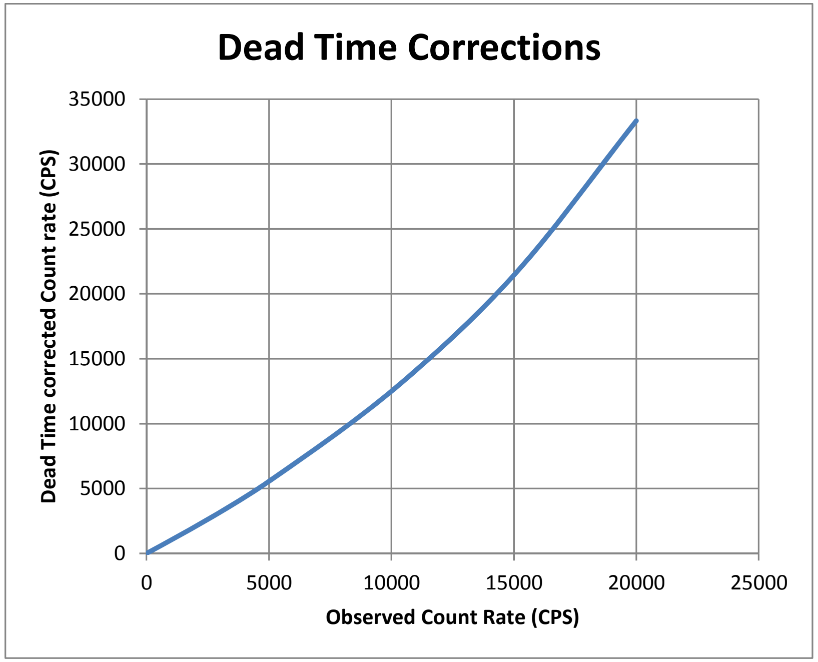
$$N = \frac{n}{(1 - n\tau)}$$

Dead Time Correction where:

N = true or corrected count rate

n = observed count rate

τ = dead time (can be τ_{ap})



Dead time calculation

- **Two pit method**

$$\tau_{ap} = \left(\frac{L-HR}{LH(1-R)}\right)$$

TWO PIT Method, where:

τ_{ap} = approximate dead time
L= observed peak count rate in lower grade hole
H=observed peak count rate in higher grade hole
R= ratio of low grade to high grade hole (chemical %)

- **Two source method**

$$\tau_{ap} = \frac{2\,(n_1+n_2-n_{12})}{[(n_1+n_2)n_{12}]}$$

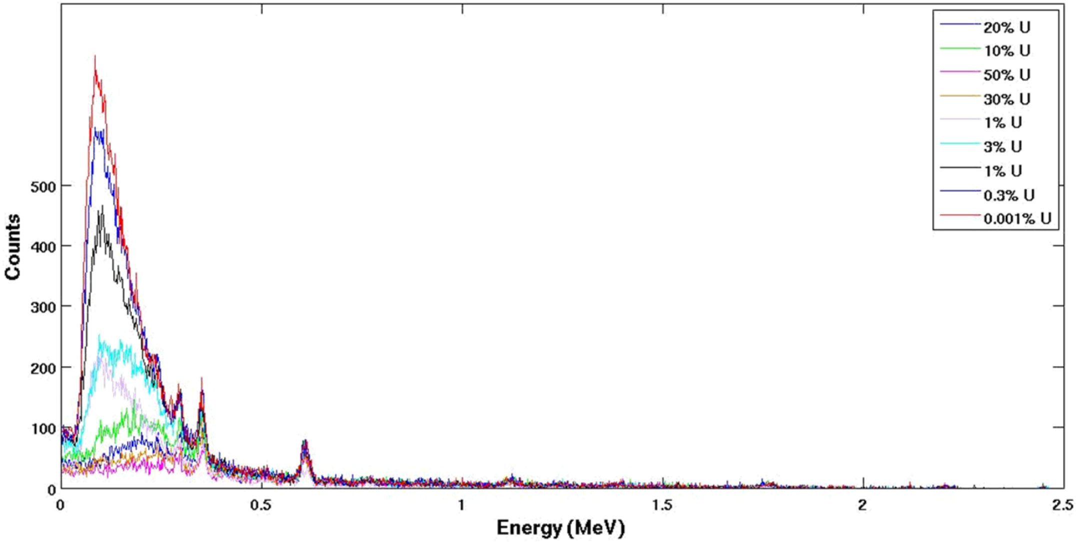
Two Source Method, where:

τ_{ap} = approximate dead time
n_1 = count rate from source 1
n_2 = count rate from source 2
n_{12} = count rate from source 1 and 2 present

- **Kohman Method (1947)**
  - Application of a least squares fit solution to multiple offsets of the Two Source Method

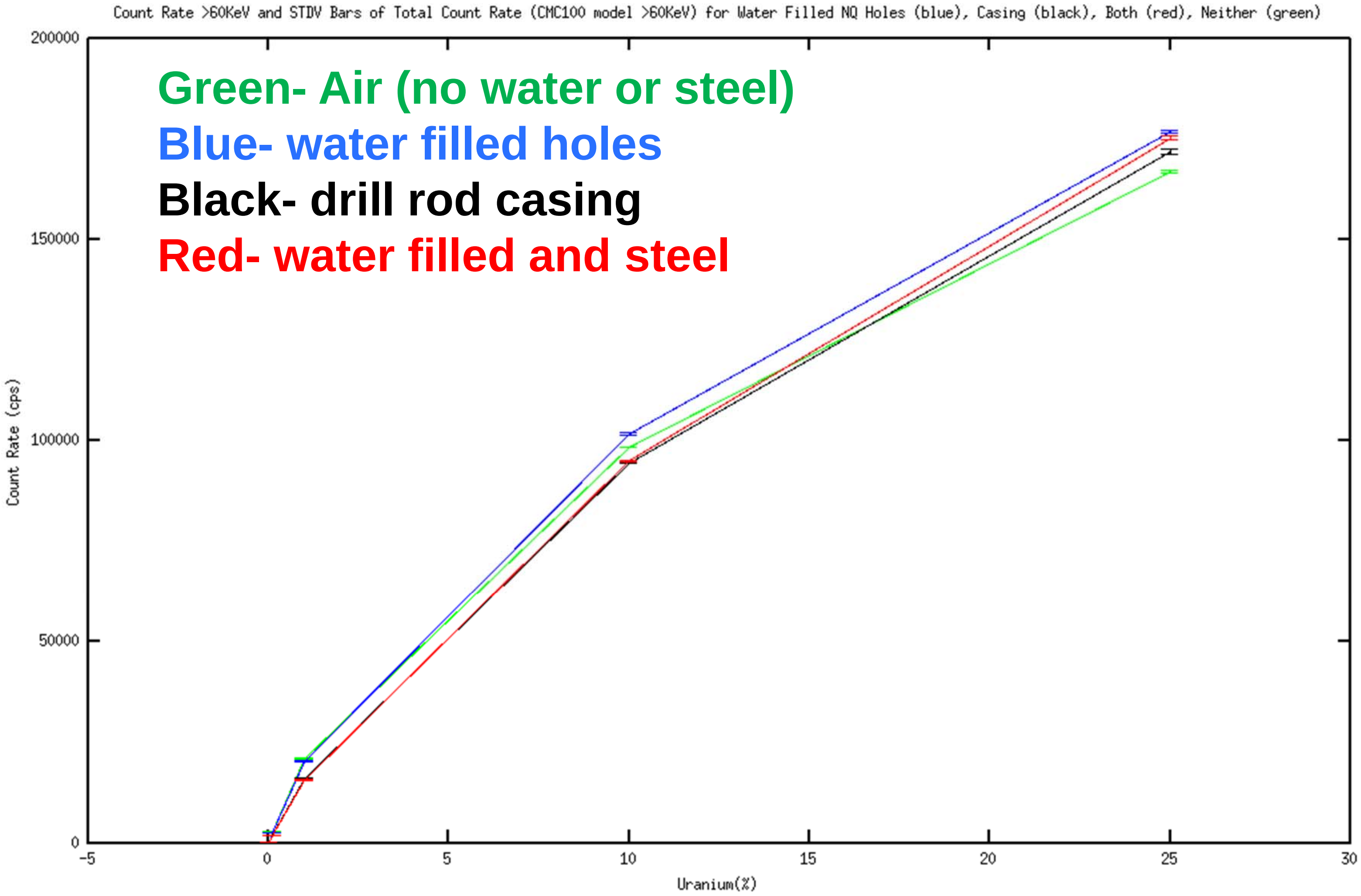
Z-effect

- The Z-effect refers to the increasing adsorption of low-energy gamma-rays (<600 keV) due to the increased photoelectric adsorption of higher atomic number (Z) elements, such as U itself.
- Due to increase of large-Z atoms with increasing Uranium Grade
- Absorption of low energy scattering, decreasing the expected count rate with uranium grade
- Causes significant underestimation of Uranium Grades when using gamma probe equivalency
- Can be removed through shielding (Pb, Cd, Cu)
- Use energy threshold



Steel and Water correction

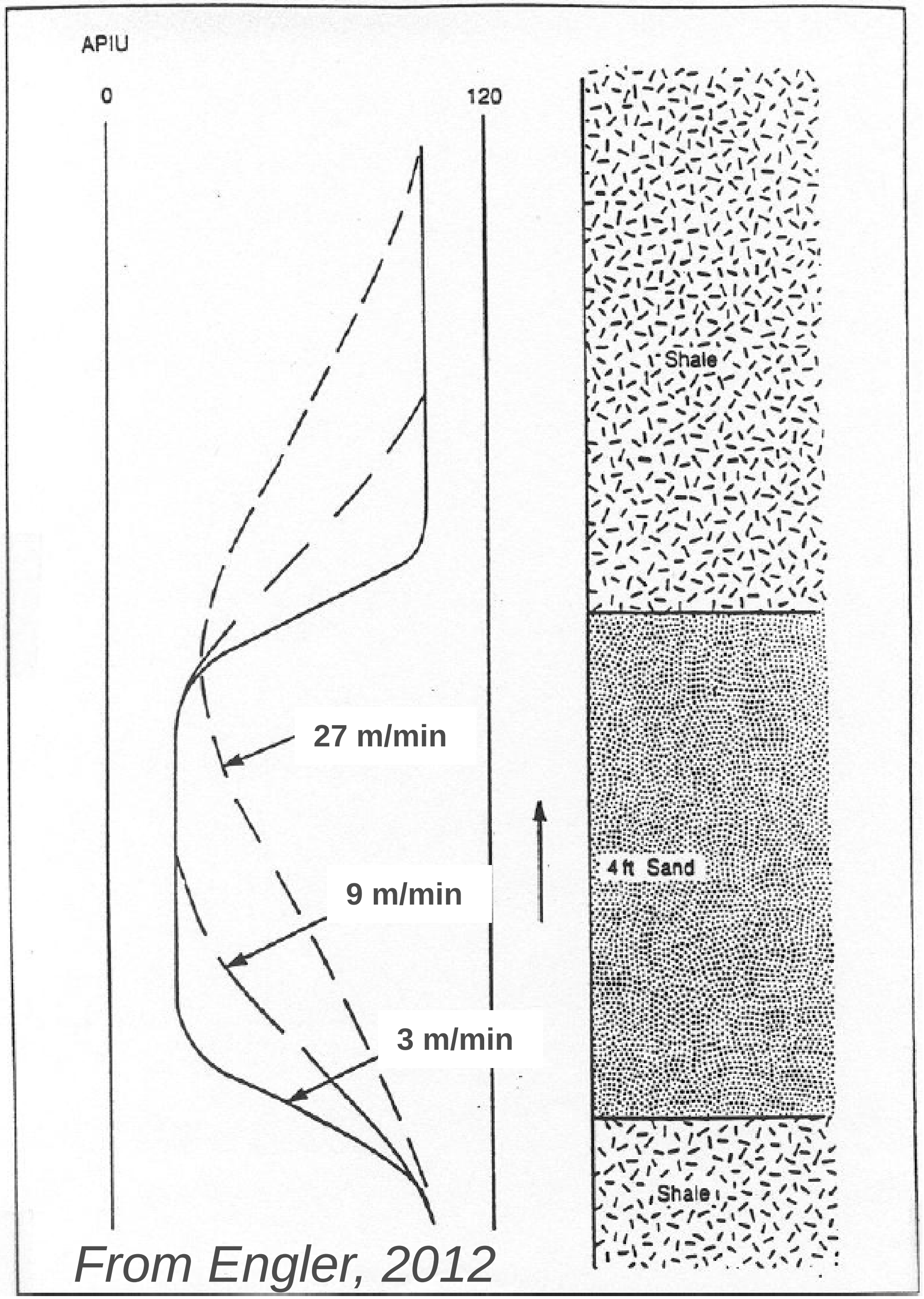
- **Correction factors for water and steel vary with the Uranium Concentration**



Green- Air (no water or steel)
Blue- water filled holes
Black- drill rod casing
Red- water filled and steel

Speed of logging

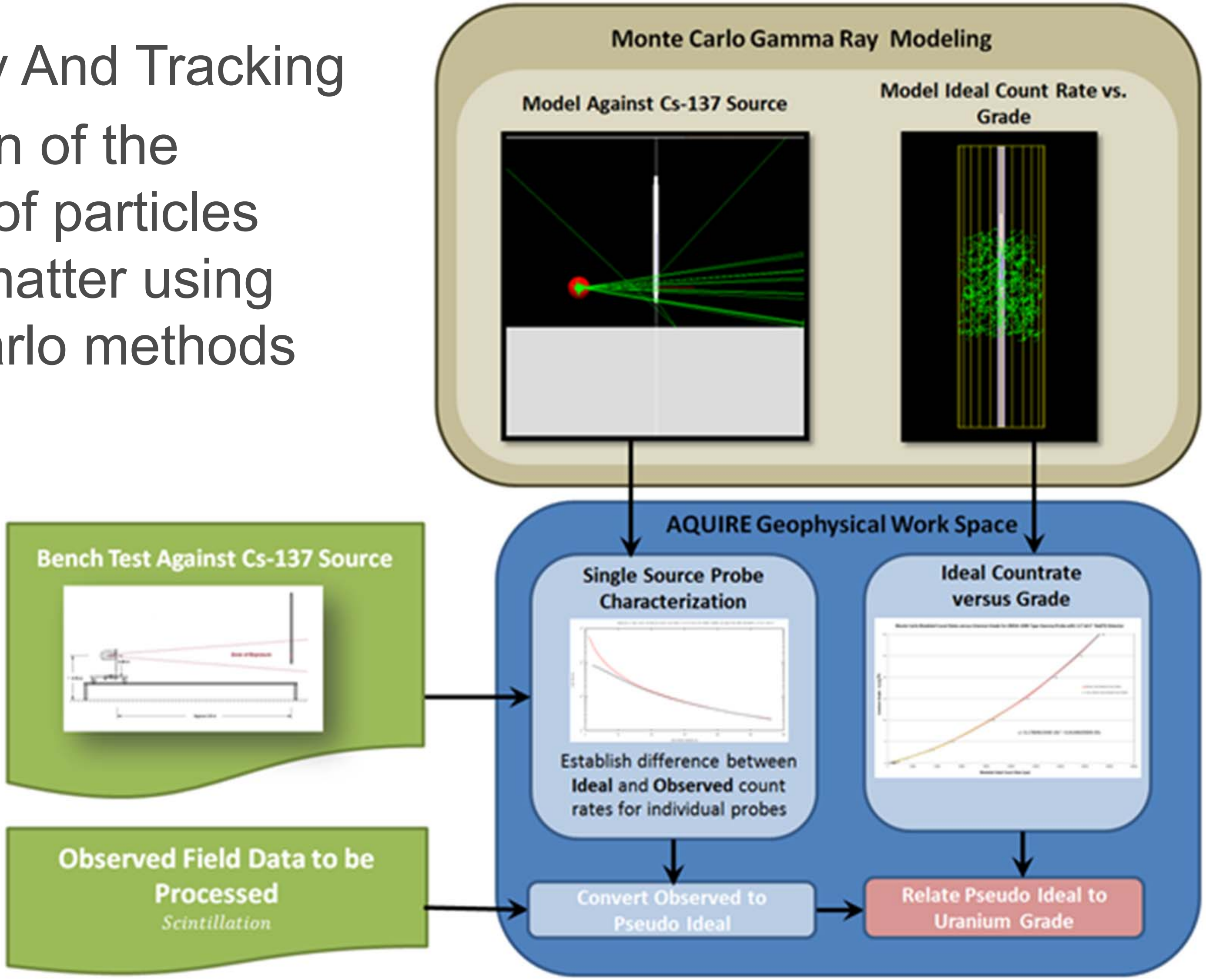
- Increased logging speed will create a shift in the peak of an anomaly in the logging direction and may completely miss thin beds.



From Engler, 2012

Virtual test pits- Geant4 Modelling

- GeoMetry And Tracking
- Simulation of the passage of particles through matter using Monte Carlo methods



Monte Carlo Gamma Ray Modeling

Model Against Cs-137 Source

Model Ideal Count Rate vs. Grade

AQUIRE Geophysical Work Space

Single Source Probe Characterization

Establish difference between **Ideal** and **Observed** count rates for individual probes

Ideal Countrate versus Grade

Bench Test Against Cs-137 Source

Observed Field Data to be Processed

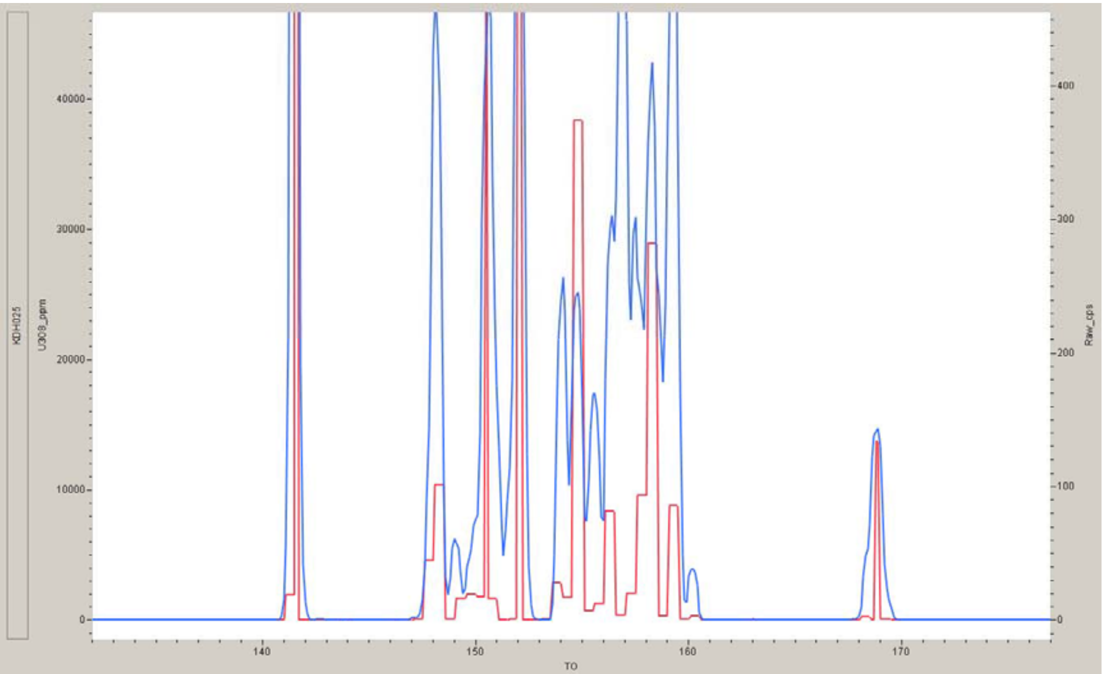
Scintillation

Convert Observed to Pseudo Ideal

Relate Pseudo Ideal to Uranium Grade

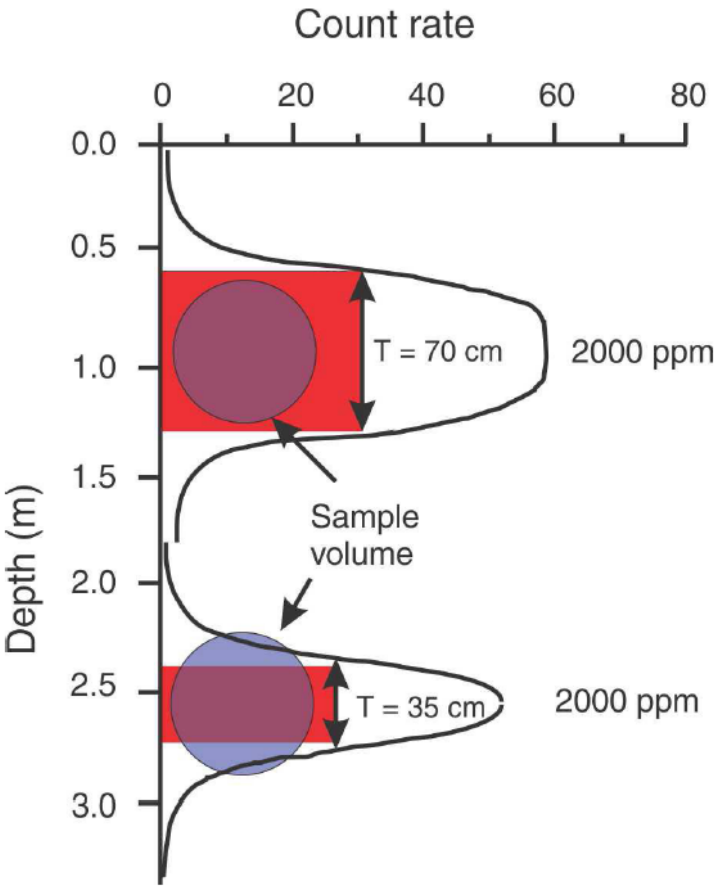
Why does Assay grade not 100% correlate to gamma eU

- Shoulder effect
- Depth off-set between probe and assay peaks
- Anomalies (i.e. peaks) in probe data not supported by drill core mineralization



Why does Assay grade not 100% correlate to gamma eU

- the orders of magnitude difference in sample volume (probe measures gamma radiation emanating from spheres of influence up to 1 m diameter whereas drill cores are usually 8-10 cm. in diameter)
- variability of grade in the interrogation volume in the natural environment
- variability of disequilibrium in the interrogation volume in the natural environment



From Mwenifumbo and Mwenifumbo , 2013

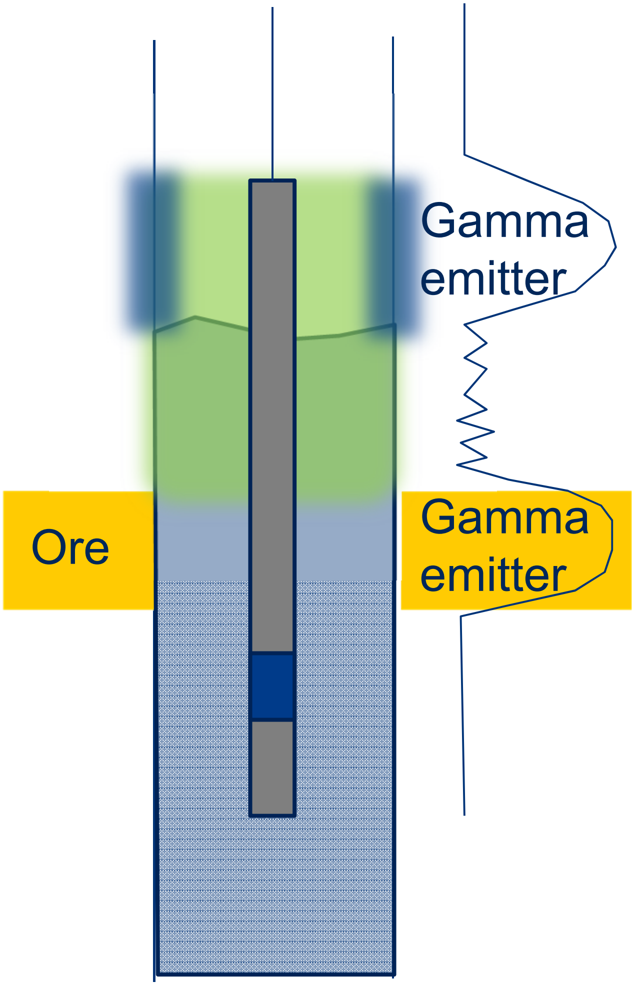
Radon issues

- Radioactive daughter product
- Half life of only four days
- Heavy gas – denser than air
- Soluble in water – can move 100's of meters in solution
- Rn is NOT a gamma emitter so no problem as long as you probe soon after drilling.

$$\boxed{\mathbf{Rn} \rightarrow \mathbf{Po} \rightarrow \mathbf{Pb}}$$

3.8 days **3 mins**

- This Pb isotope is a solid and fixes onto clay minerals on drillhole wall and Pb is a gamma emitter!!!!



Uranium equilibrium /disequilibrium

Equilibrium: when the decay series is in equilibrium the gamma radiation emitted by the decay of daughter products **<u>is</u>** *proportional* to the amount of uranium present. Typically 1 million years.

Disequilibrium: when the decay series is in disequilibrium the gamma radiation emitted by the decay of daughter products is **<u>NOT</u>** *proportional* to the amount of uranium present.

Uranium equilibrium /disequilibrium

Highly mobile elements: in solution or as a gas

First significant gamma emission

Isotope	Emission	Half-life
U^{238}	α	4.507 x10^{9} years
Th^{234}	β	24.1 days
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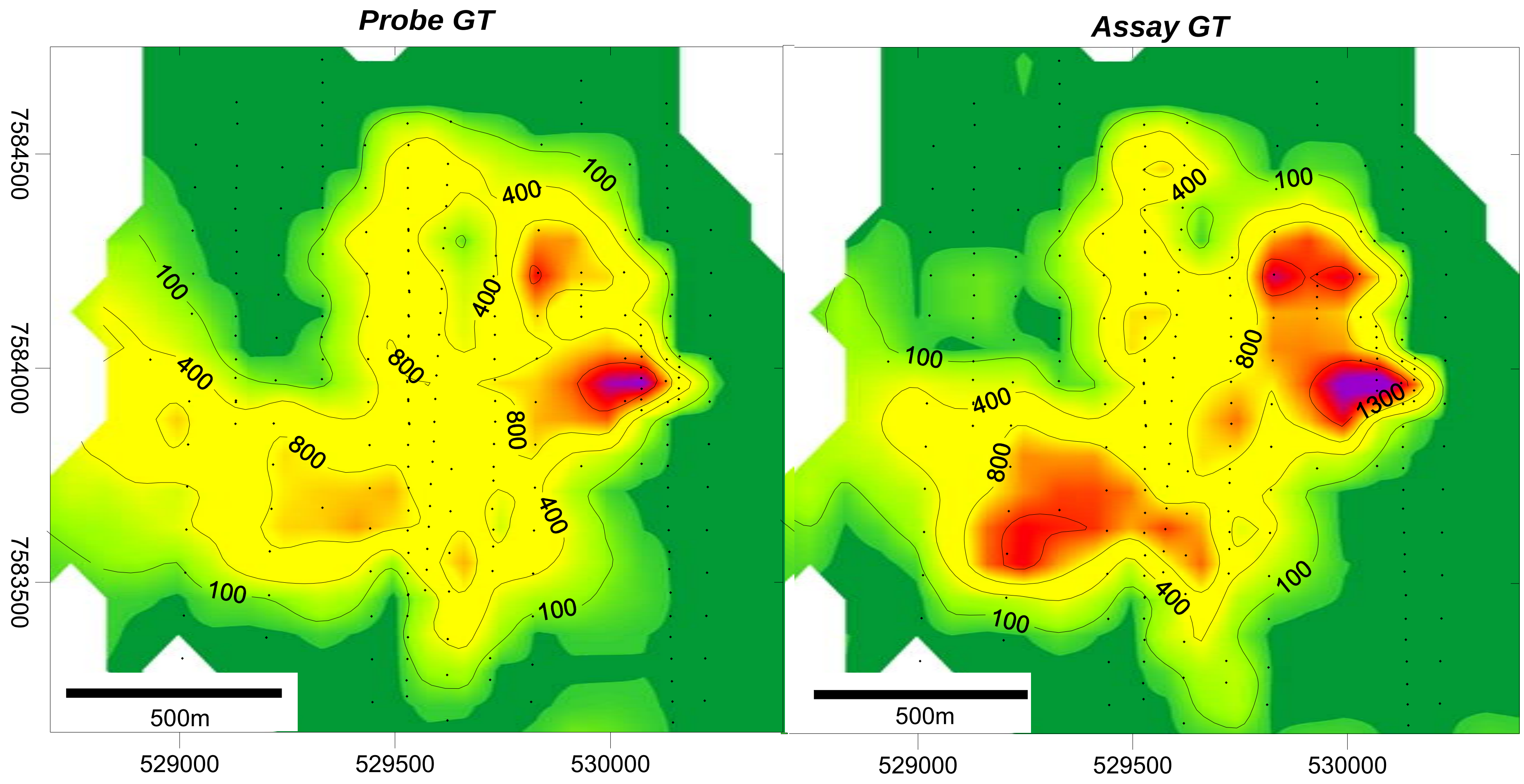
Example of disequilibrium

An example from Botswana



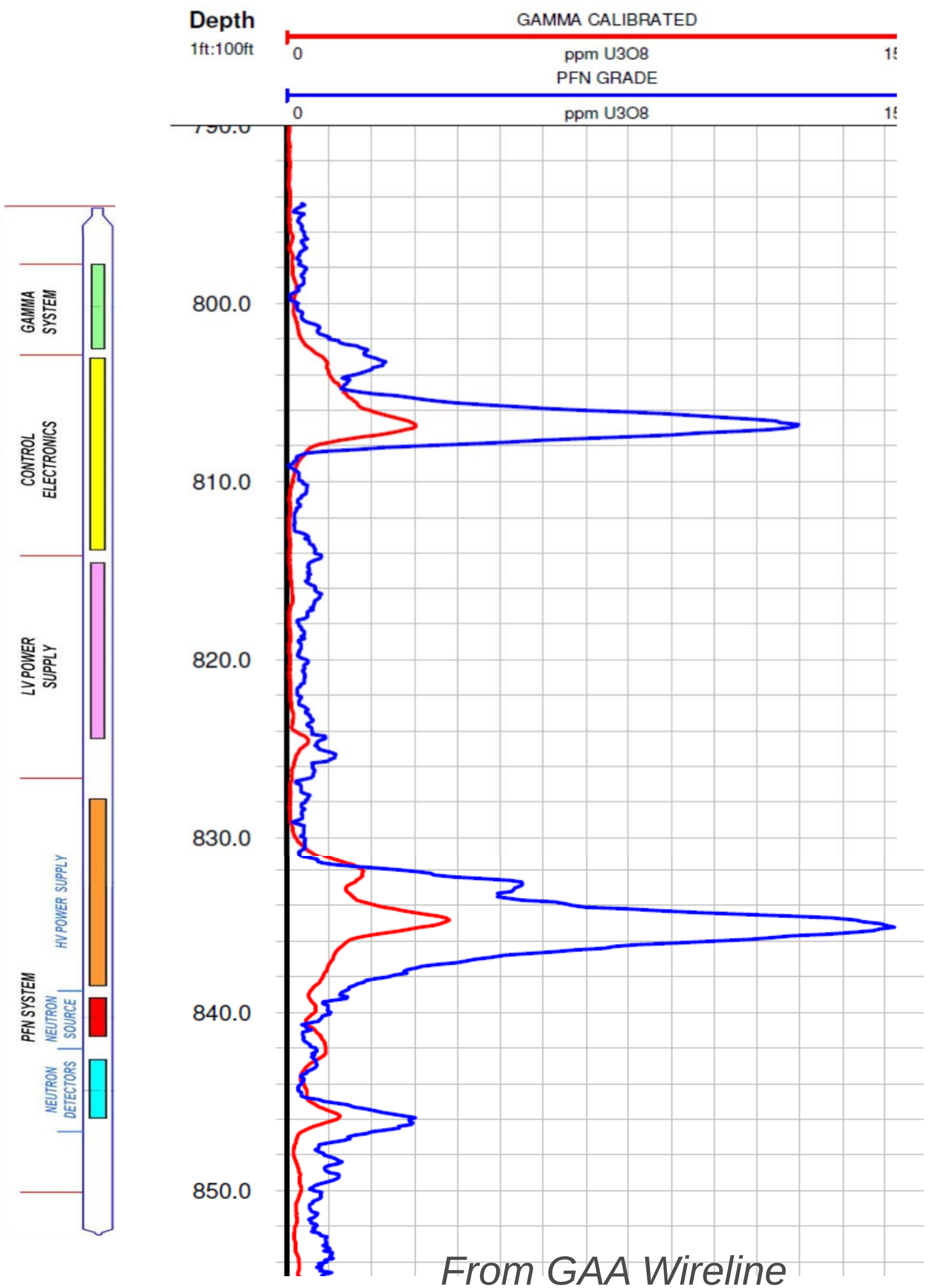
Probe GT

Assay GT

From A-Cap Resources Release

Prompt Fission Neutron (PFN)

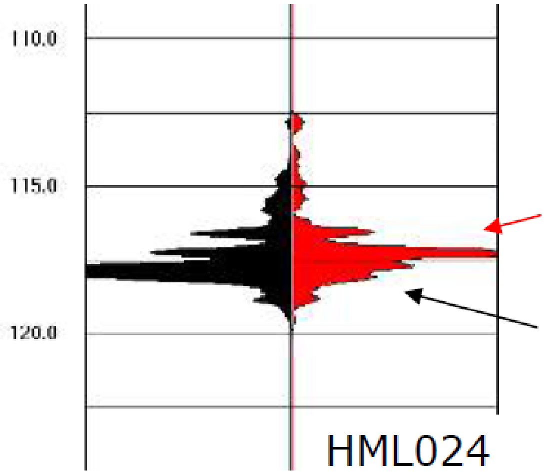
- Designed to over disequilibrium issues
- PFN directly measures the uranium using a pulsed neutron source
    - Generates neutrons that causes fission in the uranium
    - Systems measures the neutrons returning to the detector system
- Expensive, high maintenance system
- Requires specialist licencing



From GAA Wireline

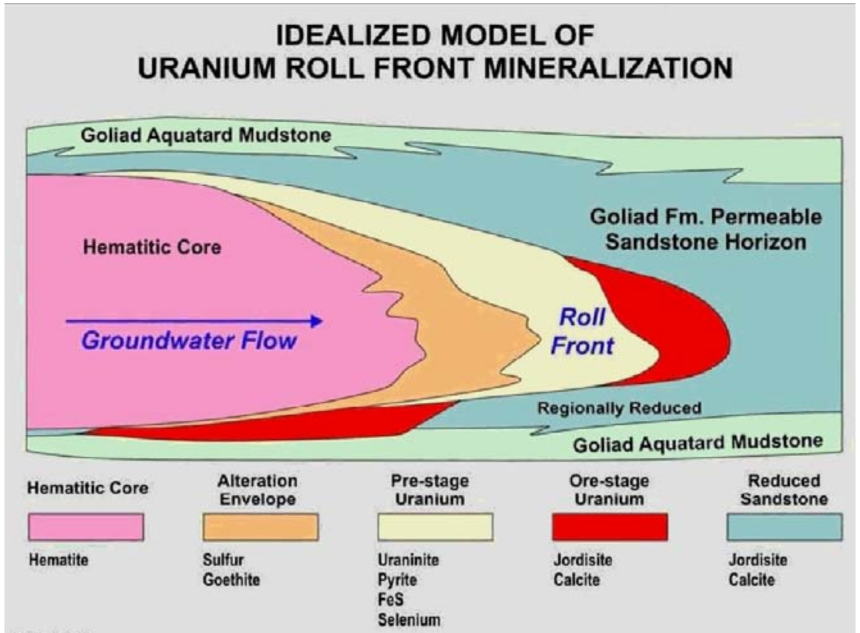
Prompt Fission Neutron

eU3O8 | pU3O8



PFN > Gamma

Gamma > PFN

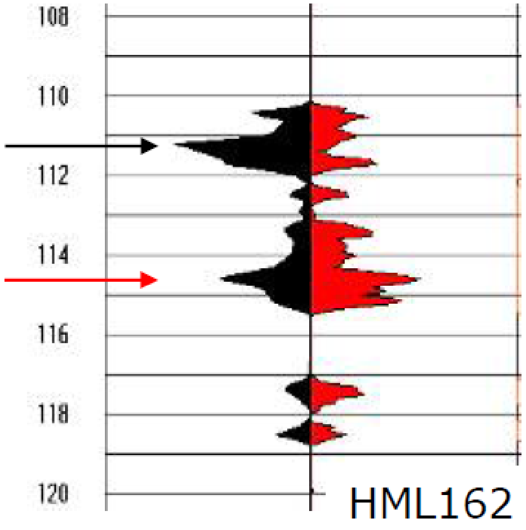


From www.sec.gov.au

eU3O8 | pU3O8

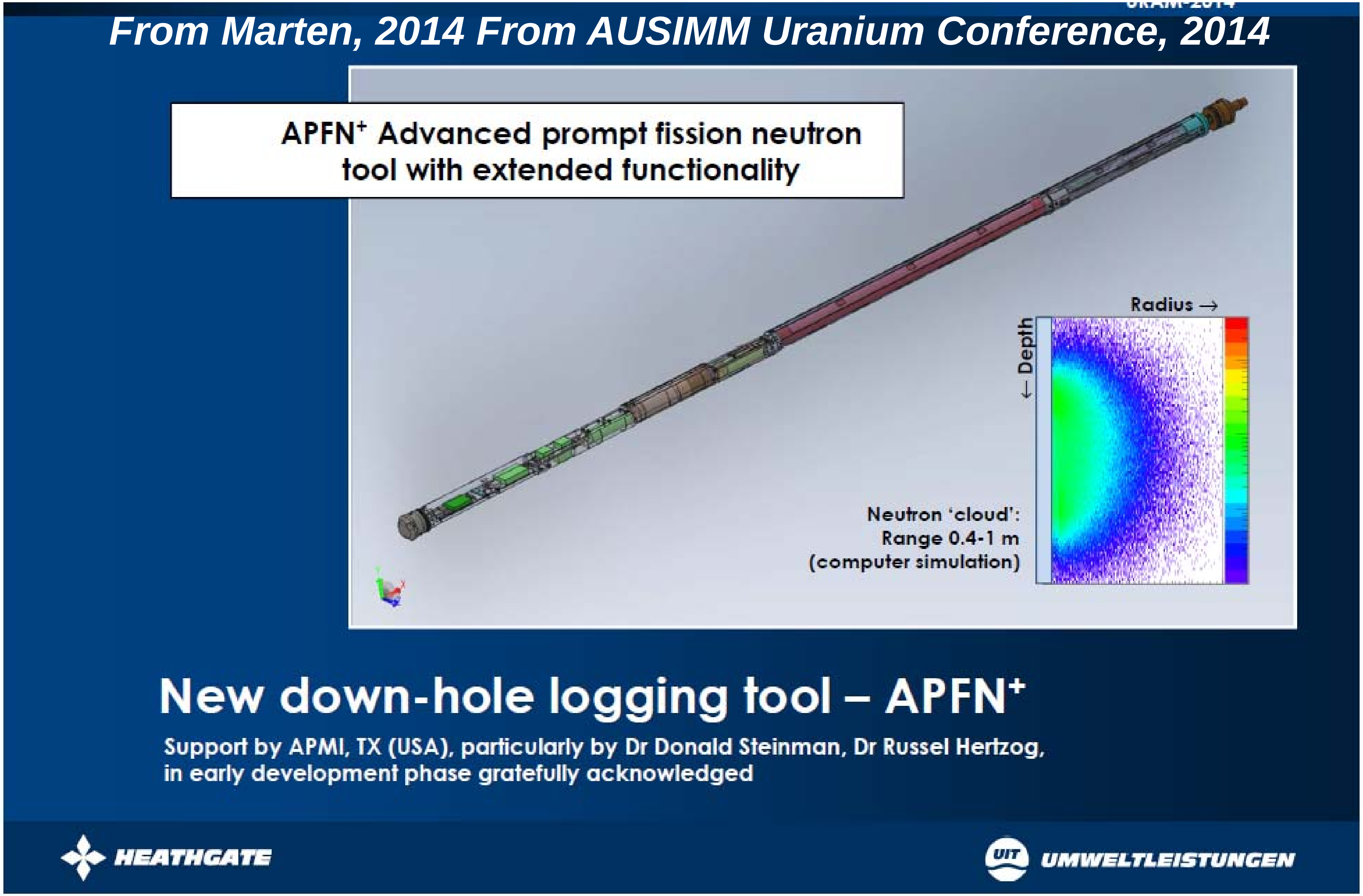
Gamma > PFN

PFN > Gamma



From Skidmore, 2009
SMEDG Symposium

New developments



From Marten, 2014 From AUSIMM Uranium Conference, 2014

APFN^{+} Advanced prompt fission neutron tool with extended functionality

Neutron 'cloud':
Range 0.4-1 m
(computer simulation)

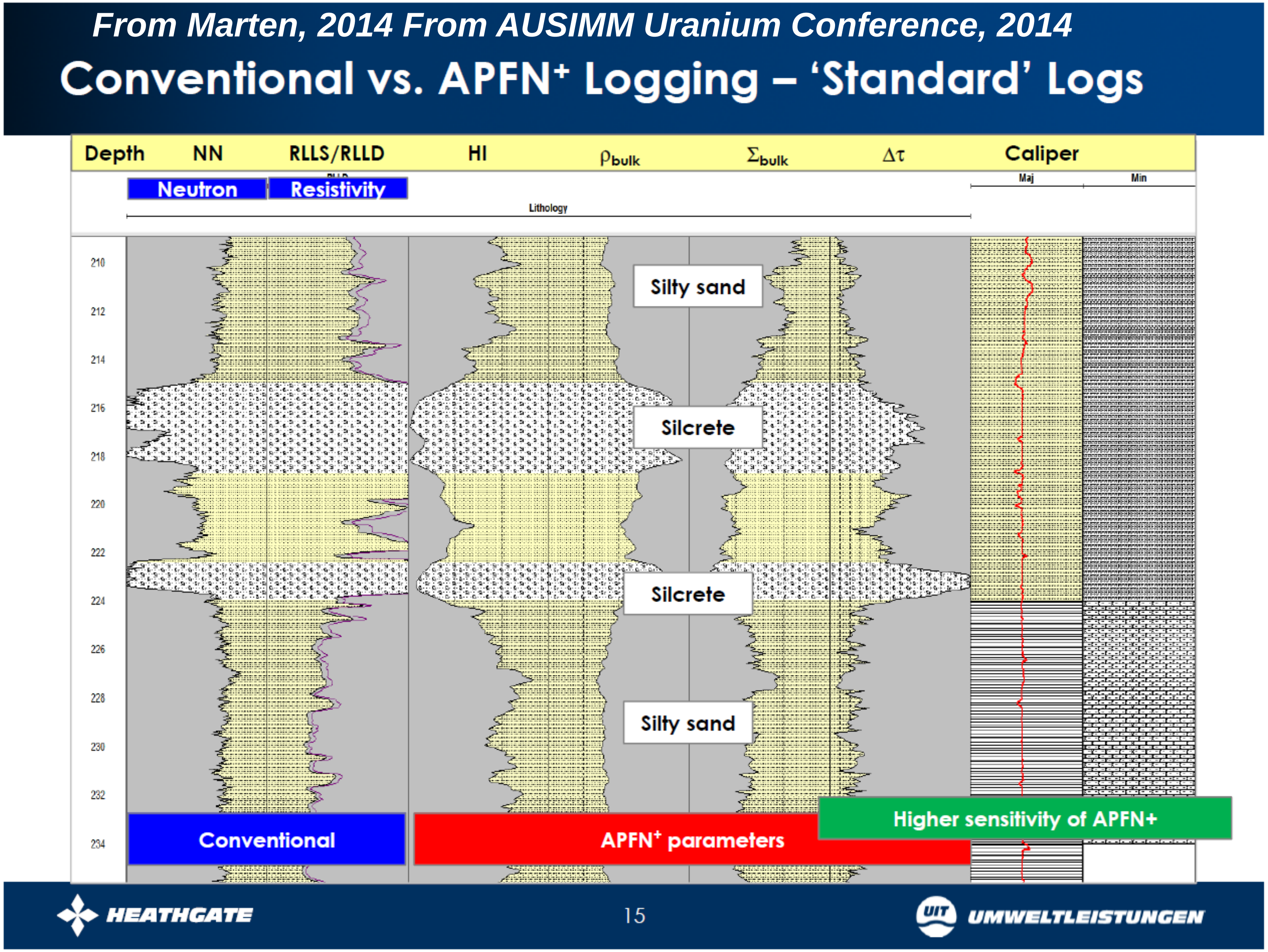
New down-hole logging tool – APFN^{+}

Support by APMI, TX (USA), particularly by Dr Donald Steinman, Dr Russel Hertzog, in early development phase gratefully acknowledged

HEATHGATE

UMWELTLEISTUNGEN

APFN+



From Marten, 2014 From AUSIMM Uranium Conference, 2014

Conventional vs. APFN$^+$ Logging – 'Standard' Logs

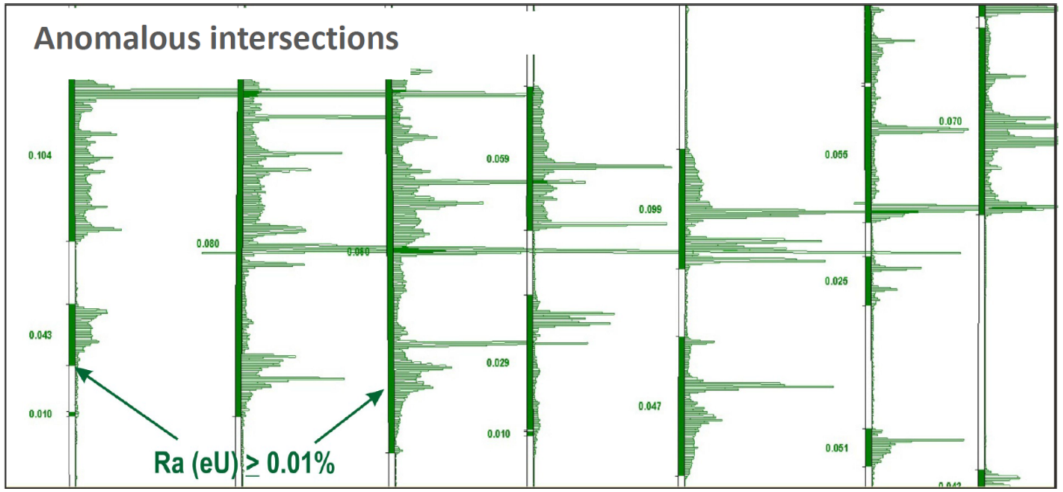
Conventional

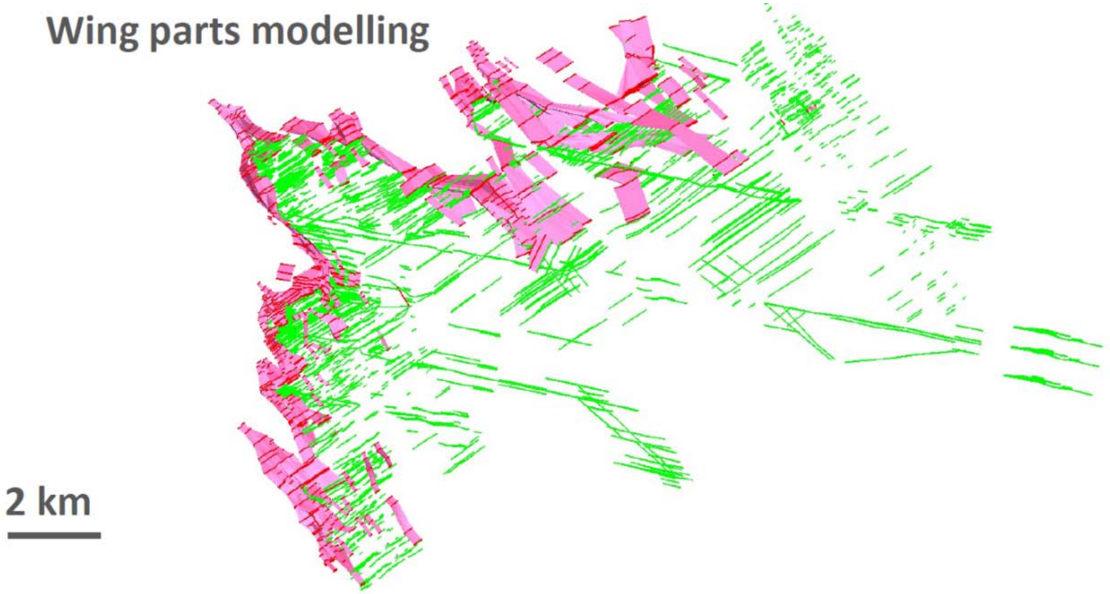
APFN$^+$ parameters

Higher sensitivity of APFN+

HEATHGATE 15 UIT UMWELTLEISTUNGEN

Example of Mine planning using Gamma probing





Inkai Deposit
From Seredkin , 2014
Ausimm Uranium conference)

Conclusions

- **Advantages**
  - Cost effective
  - Real time uranium grade estimation during drilling
  - Accurate depth control
  - Excellent resolution compares to assay sampling
  - Estimation of uranium grades in presence of poor or non-existent core recovery.
  - Independent validation of geochemical assaying
  - Used in mine grade control
- **Vigilances**
  - Probes need to be well calibrated
  - Repeatable
  - Disequilibrium needs to be taken into account

Questions

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Cameco