Australian Government

Australian Nuclear Science and Technology Organisation

Measurement of Hydraulic Conductivity, Porosity and Lithology by Neutron Activation Borehole Logging at high spatial resolution increments

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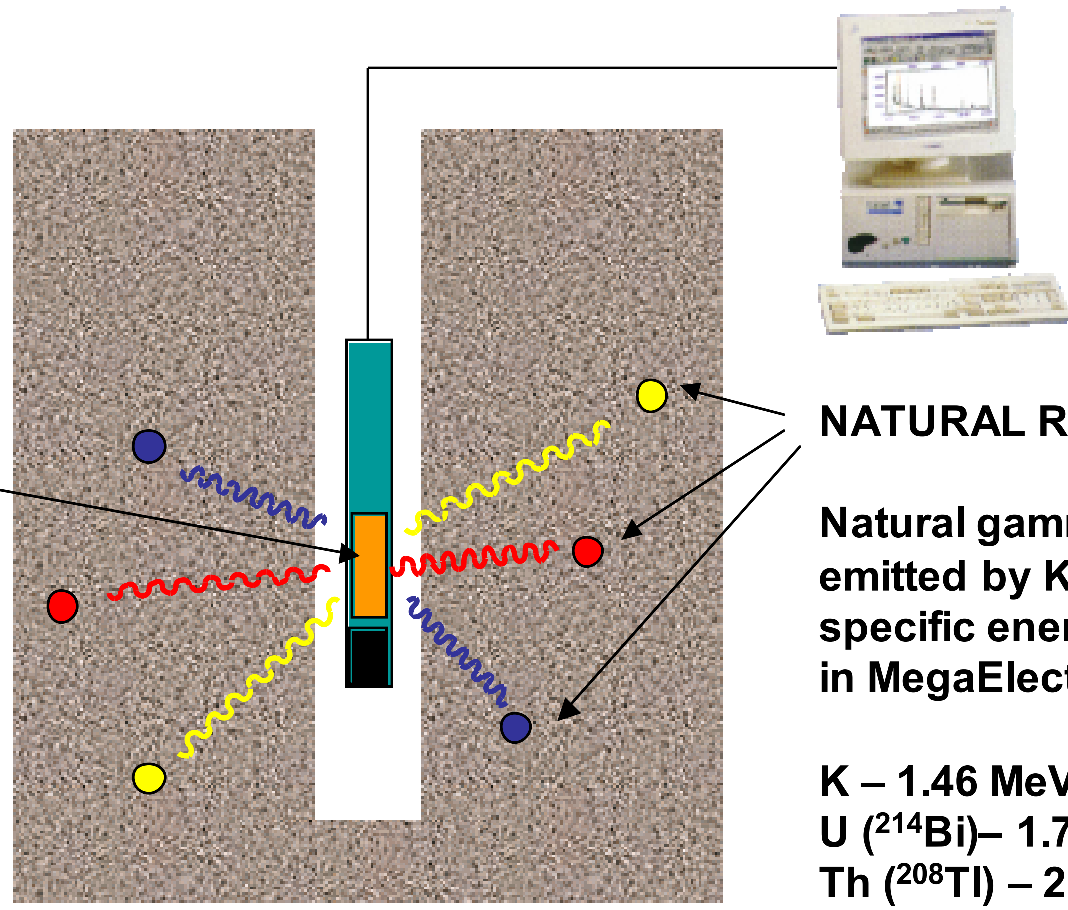
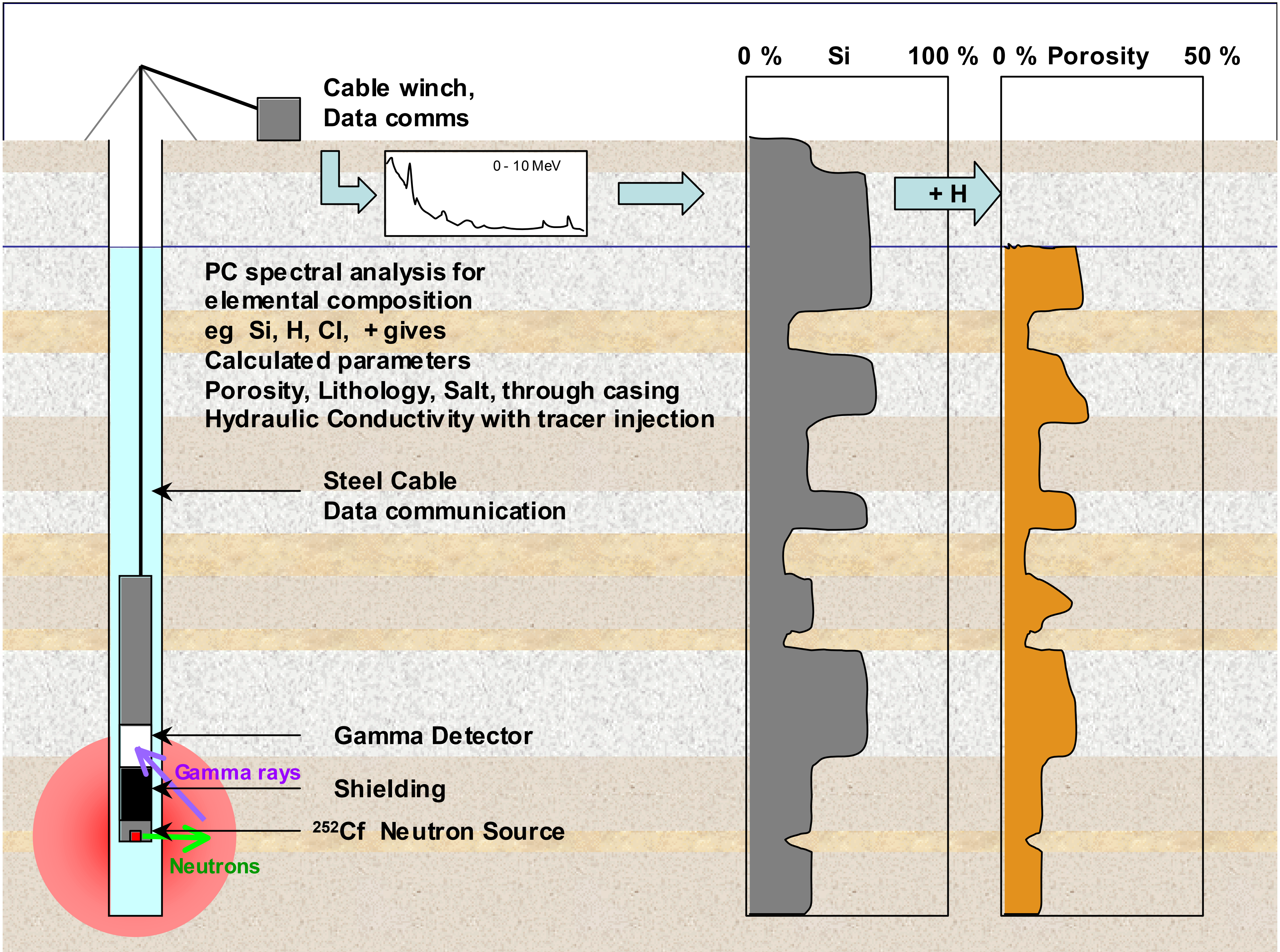
Natural Gamma Logging (passive)
Borehole configuration and measurement



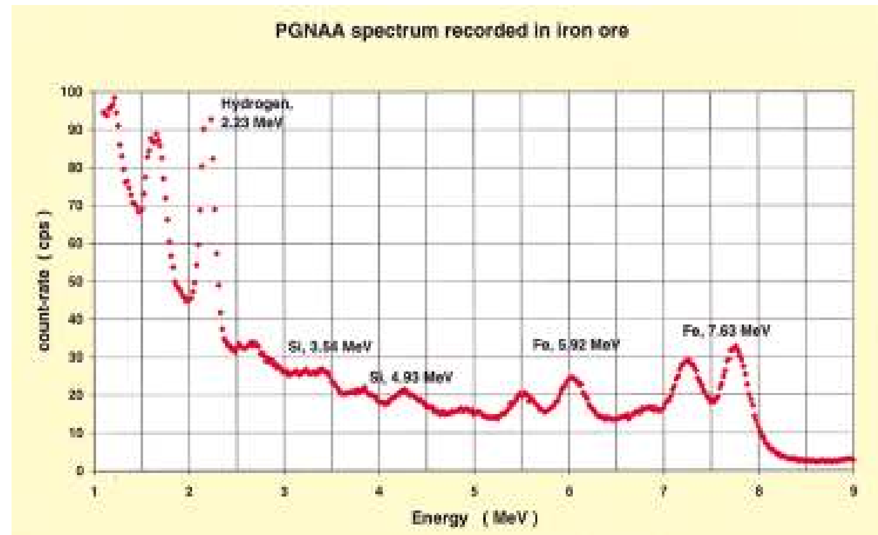
Natural gamma radiation is emitted by K, U and Th of specific energy and measured in MegaElectronvolts (MeV)

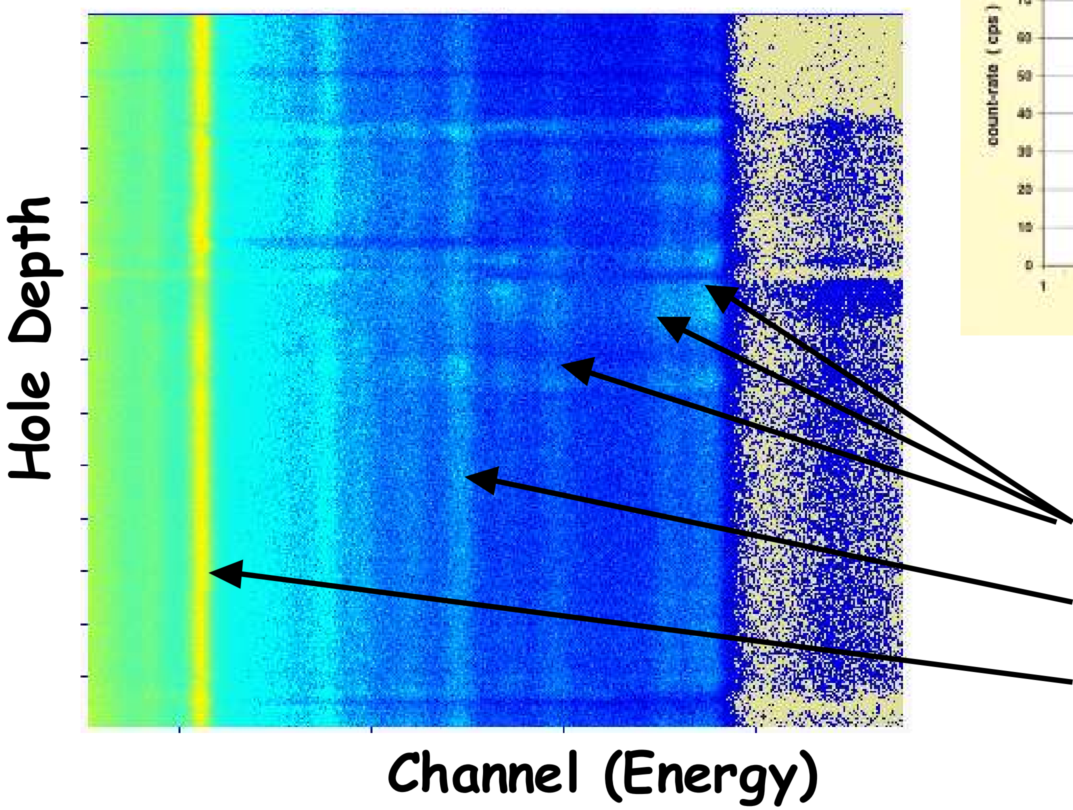
K – 1.46 MeV
U (^{214}Bi)– 1.77 MeV
Th (^{208}Tl) – 2.61 MeV



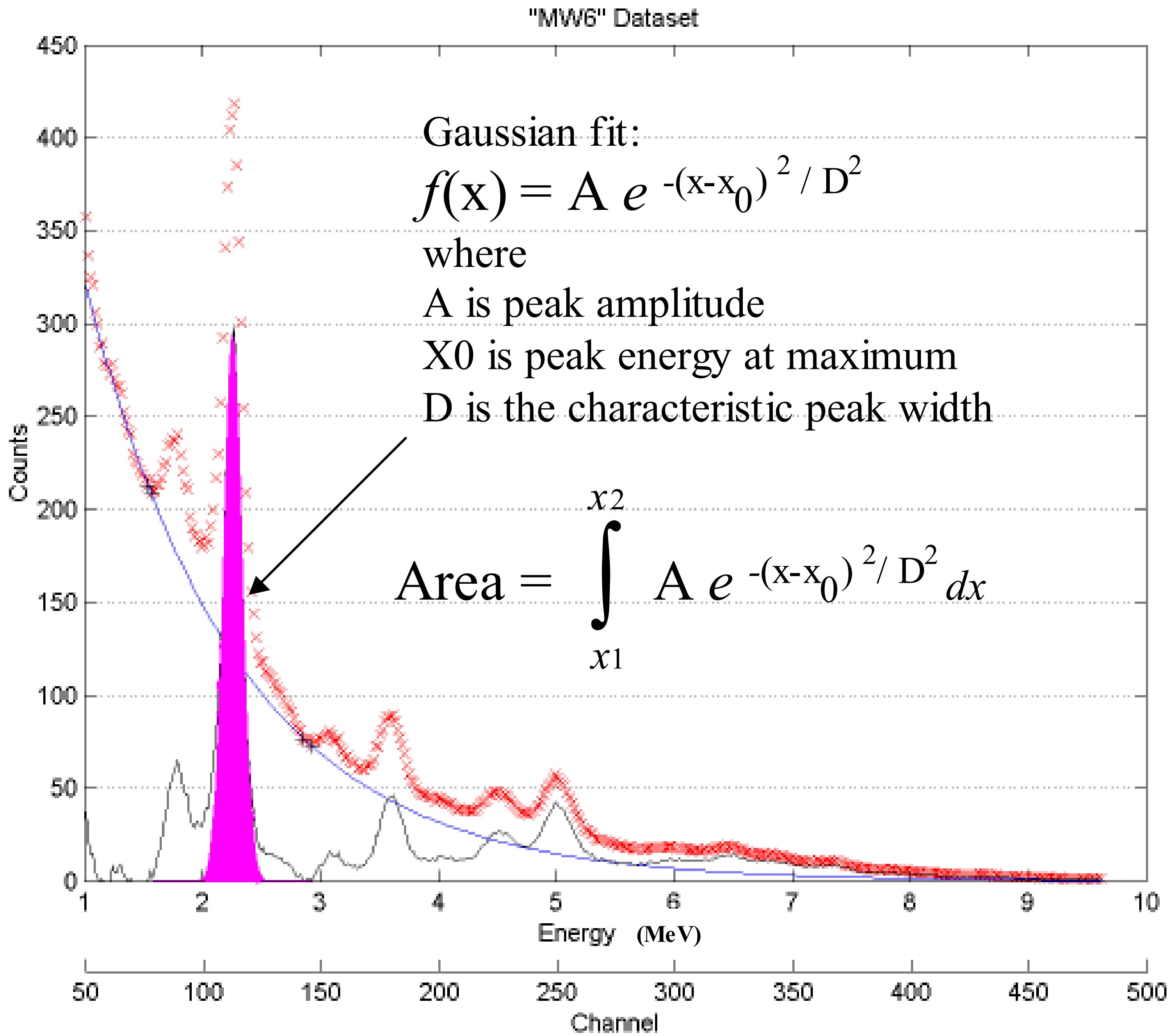
Cable winch,
Data comms
0 - 10 MeV
0 % Si 100 %
0 % Porosity 50 %
+ H
PC spectral analysis for
elemental composition
eg Si, H, Cl, + gives
Calculated parameters
Porosity, Lithology, Salt, through casing
Hydraulic Conductivity with tracer injection
Steel Cable
Data communication
Gamma Detector
Gamma rays
Shielding
252Cf Neutron Source
Neutrons

PROMPT GAMMA NEUTRON ACTIVATION ANALYSIS (PGNAA)





- Coloured to display count rate (yellow = high, brown = low)
- Fe response
- Si response
- H response (used for stabilisation)


"MW6" Dataset
Gaussian fit:
$f(x) = A\, e^{-(x-x_0)^2 / D^2}$
where
A is peak amplitude
X0 is peak energy at maximum
D is the characteristic peak width
$\text{Area} = \int_{x1}^{x2} A\, e^{-(x-x_0)^2 / D^2}\, dx$
Counts
Energy (MeV)
Channel
450
400
350
300
250
200
150
100
50
0
1
2
3
4
5
6
7
8
9
10
50
100
150
200
250
300
350
400
450
500

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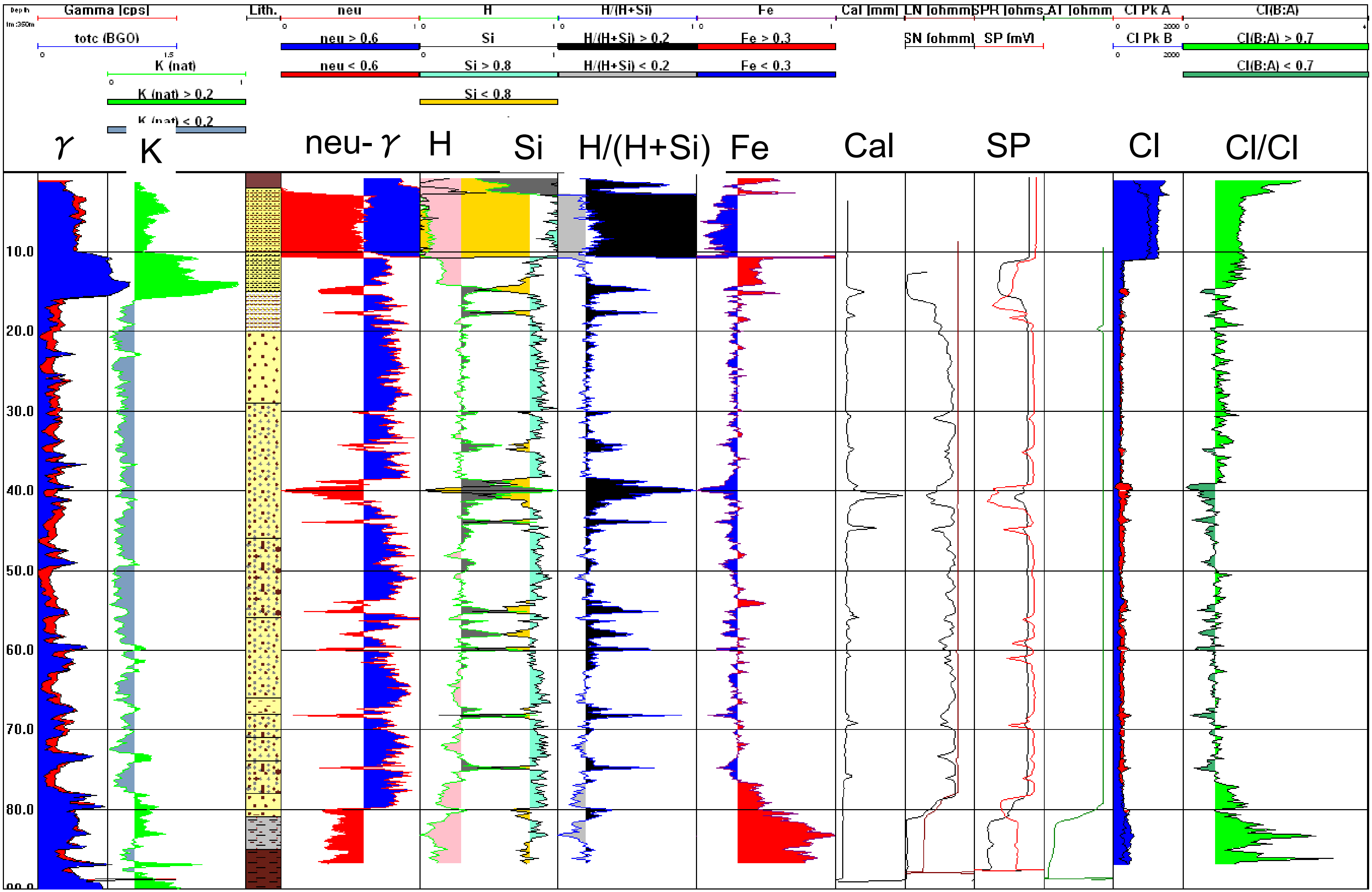
Prompt Gamma Neutron Activation Analysis

Natural Spectral Gamma: Total Counts, K-40

Bore Name: 2b
Log Date: 10/08/2005

Logged by: Chris Waring, Stuart Hankin
Tool: BGO



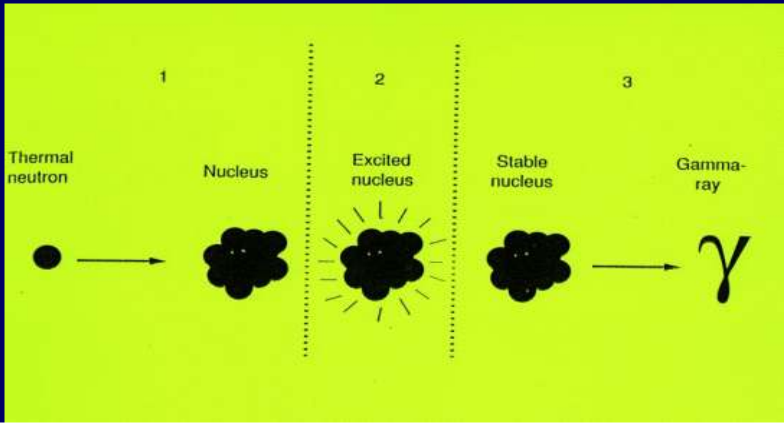
Prompt Gamma Neutron Activation Technique

- The 252Cf source emits neutrons that are thermalised after interaction with hydrogen (in water and polyethylene).

- A thermal neutron enters the nucleus and produce an unstable compound nucleus (in an excited state), which decays by emission of one or more gamma-rays.

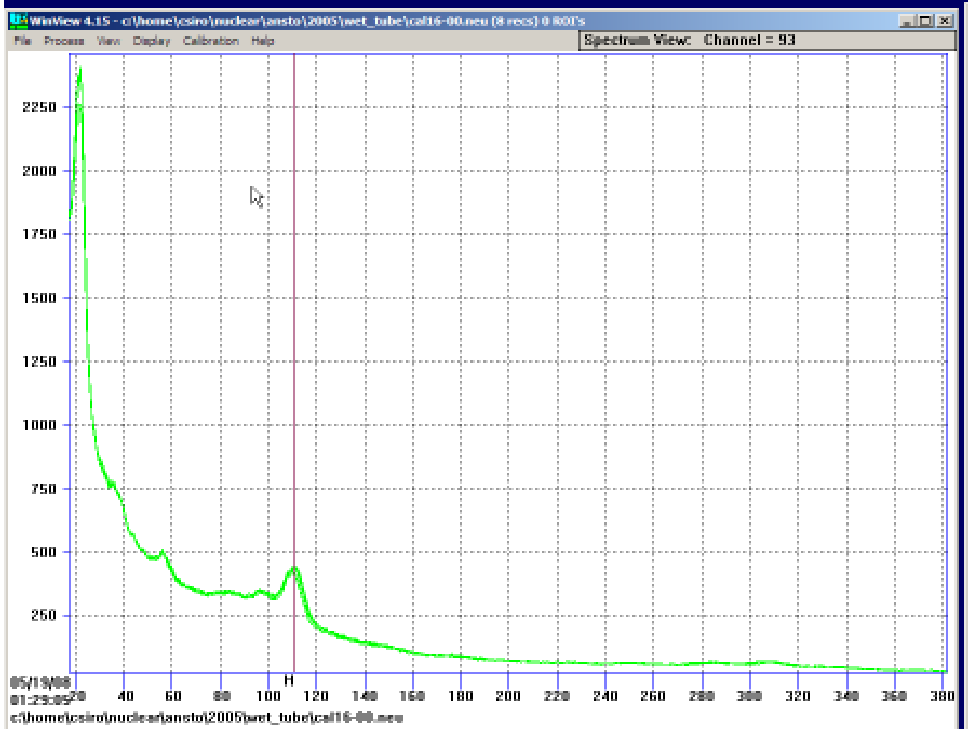
- The gamma-rays emitted have energies characteristic of the target nucleus.

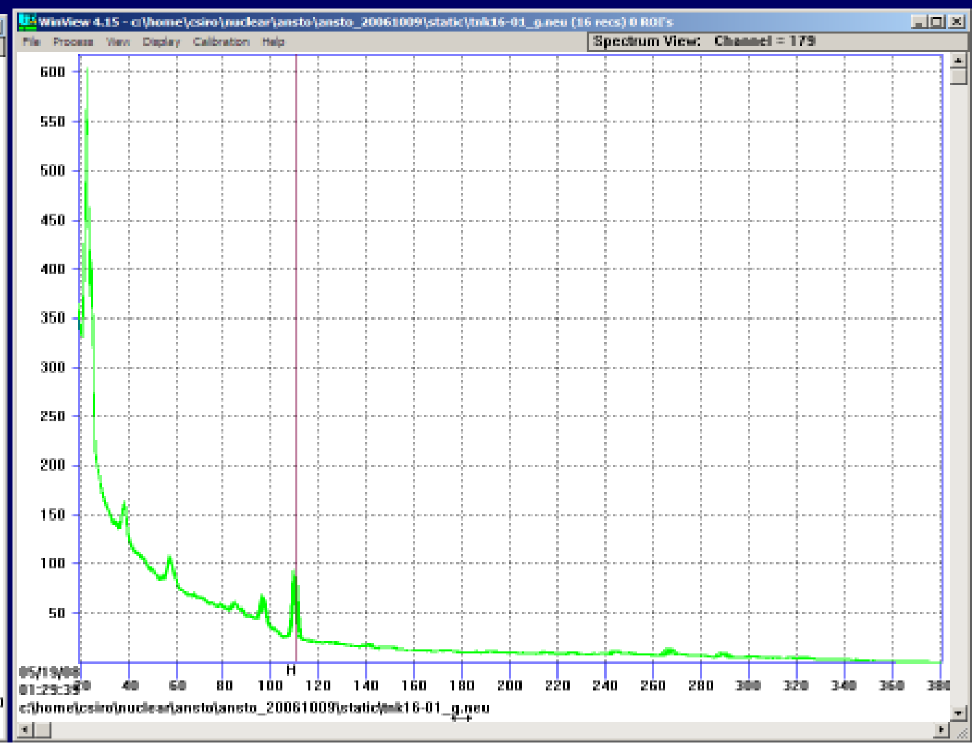
- The intensity of a given response is directly proportional to:
  - the abundance of that element,
  - the thermal neutron flux,
  - the thermal neutron capture cross section.



New Detector Technology Available

- New LaBr detectors offer performance in a range approaching high purity germanium, without the necessity for complex support electronics and cooling.
- LaBr detectors have superior resolution (<3%) compared with NaI (~6%), BGO(~12%) and have the ability to operate up to the energy range of BGO (>10MeV).
- LaBr detectors offer vastly improved spectral separation due to their excellent resolution

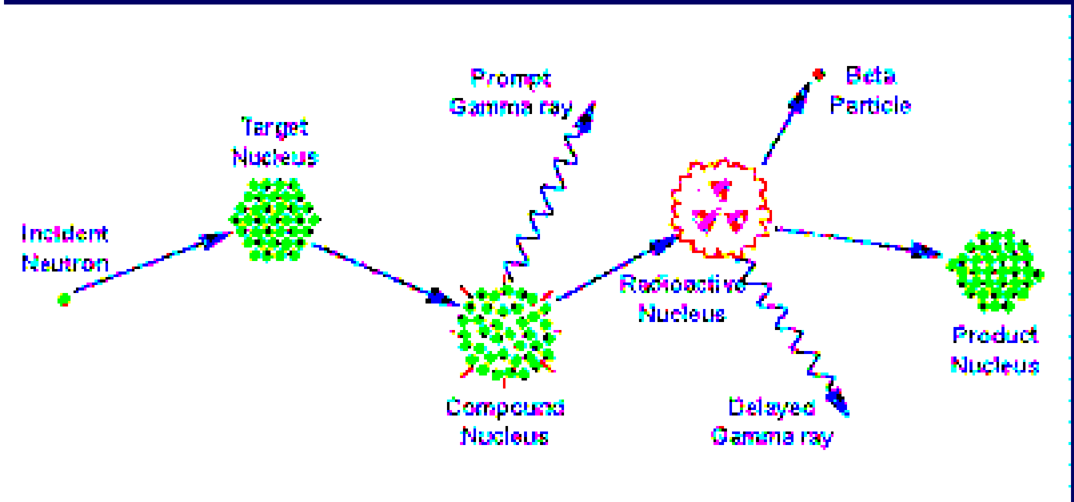




Neutron Generators

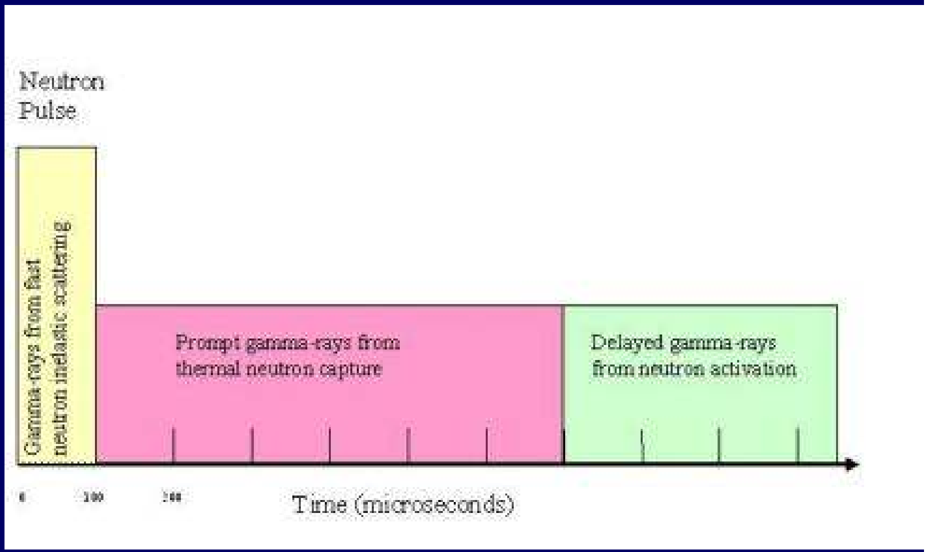
- Use either DD, DT, or TT reactions (or all 3)
  - ${}_1H^2 + {}_1H^2 \rightarrow {}_2He^3 + {}_0n^1$ (DD 2.5MeV neutron)
  - ${}_1H^2 + {}_1H^3 \rightarrow {}_2He^4 + {}_0n^1$ (DT 14.1 MeV neutron)
  - ${}_1H^3 + {}_1H^3 \rightarrow {}_2He^4 + 2{}_0n^1$ (TT ~0.5-~10MeV neutrons)
- Techniques
  - Hot Cathode [target device]
  - Cold Cathode (Penning) [target device]
  - Inertial Electrostatic Confinement (IEC) device
  - RF Ion source
- Size Limitations
  - Usually caused by HV supply size ~ 120mm

Neutron Generator Activation Physics

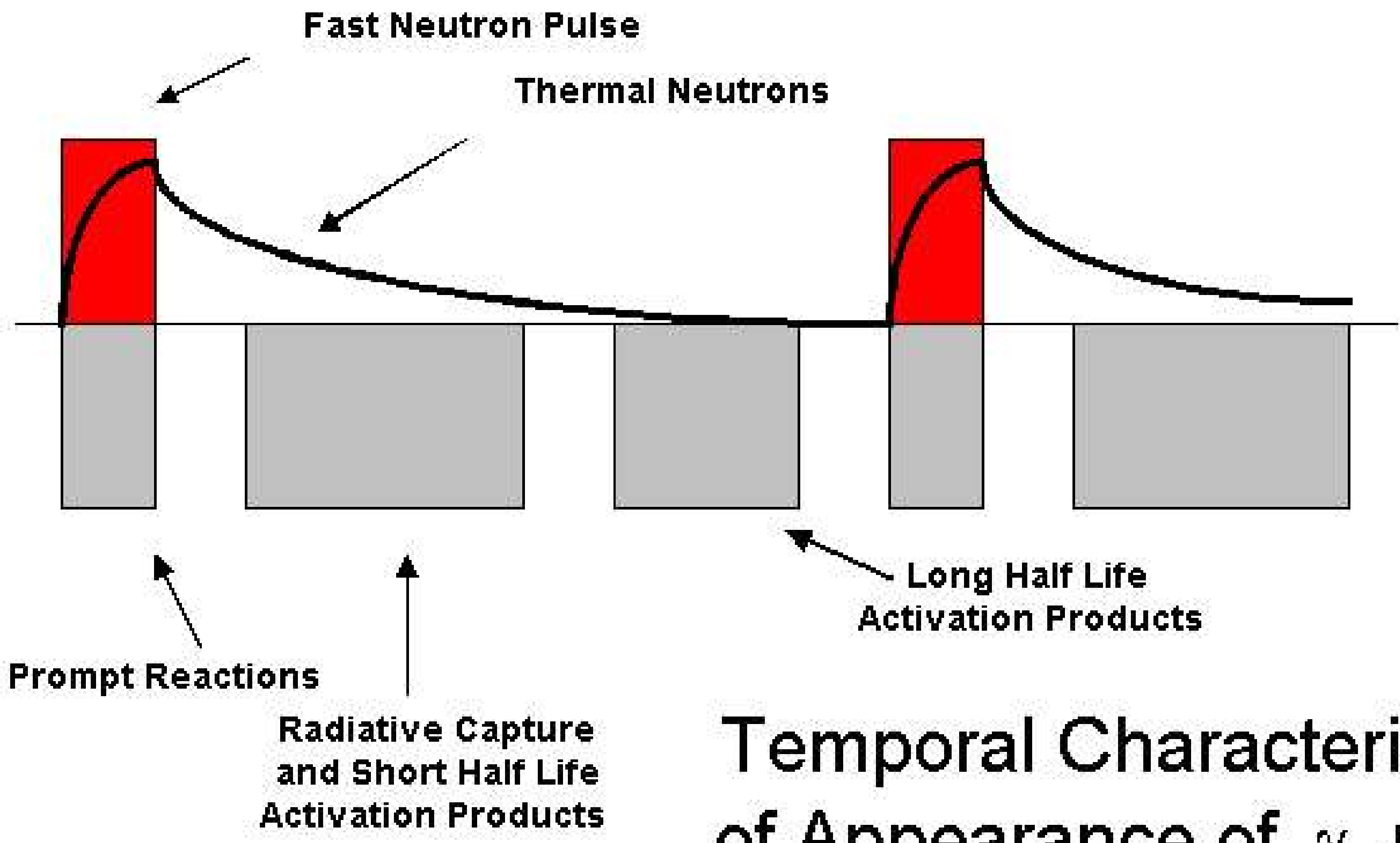


An Overview of Neutron Activation Analysis
by Michael D. Glascock
University of Missouri Research Reactor (MURR)

- Inelastic Neutron Scattering Gamma Ray Analysis (INS)
- Prompt Gamma Activation Analysis (PGNAA)
- Delayed Gamma Activation Analysis (DGNAA)
- Activated Neutron Analysis (long timescales)



Timing

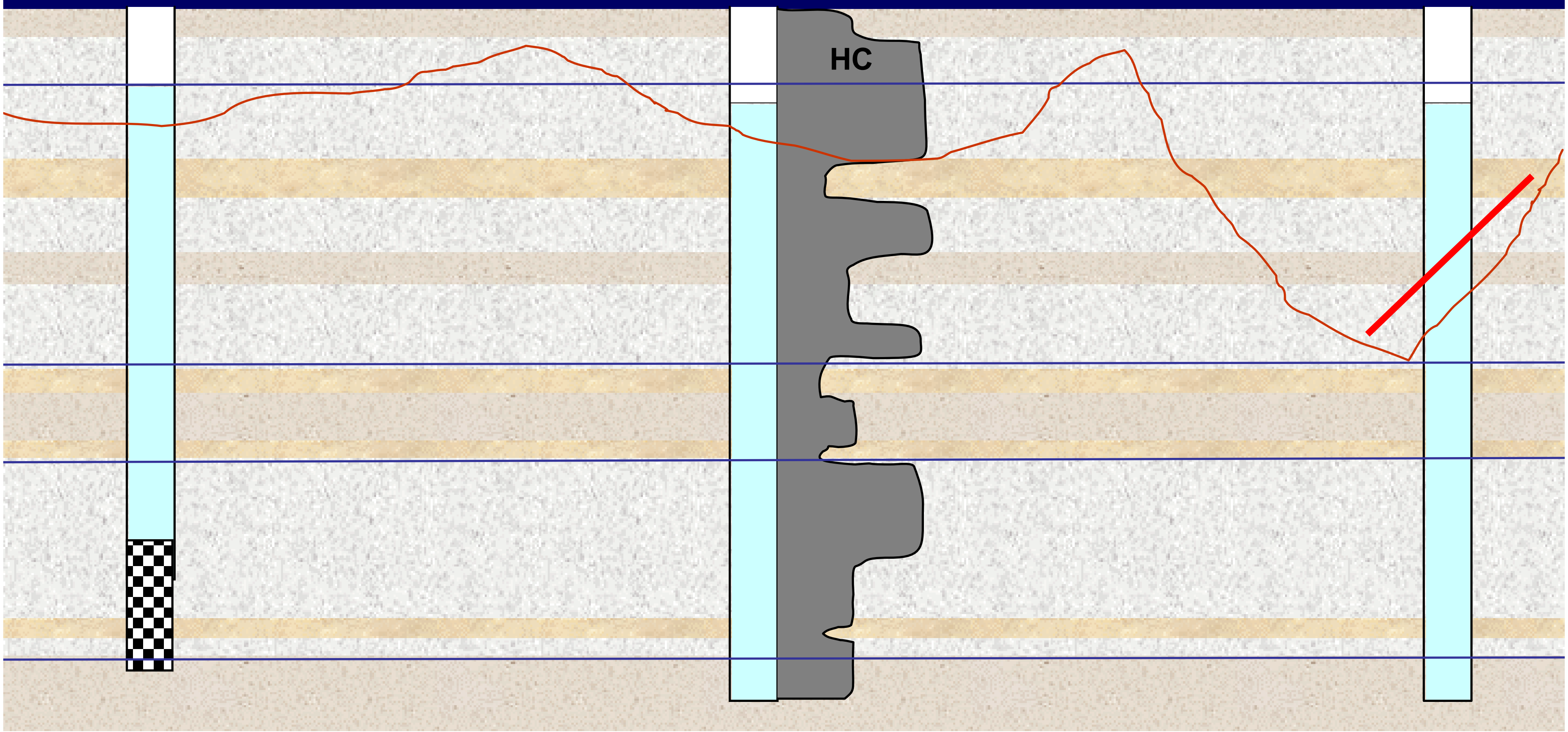


Temporal Characteristic of Appearance of γ–rays

Hydraulic Conductivity

Definition of full range of HC, enables stratigraphic correlation wrt HC

Better choice of groundwater flow model averaged stratigraphy based on measured HC values



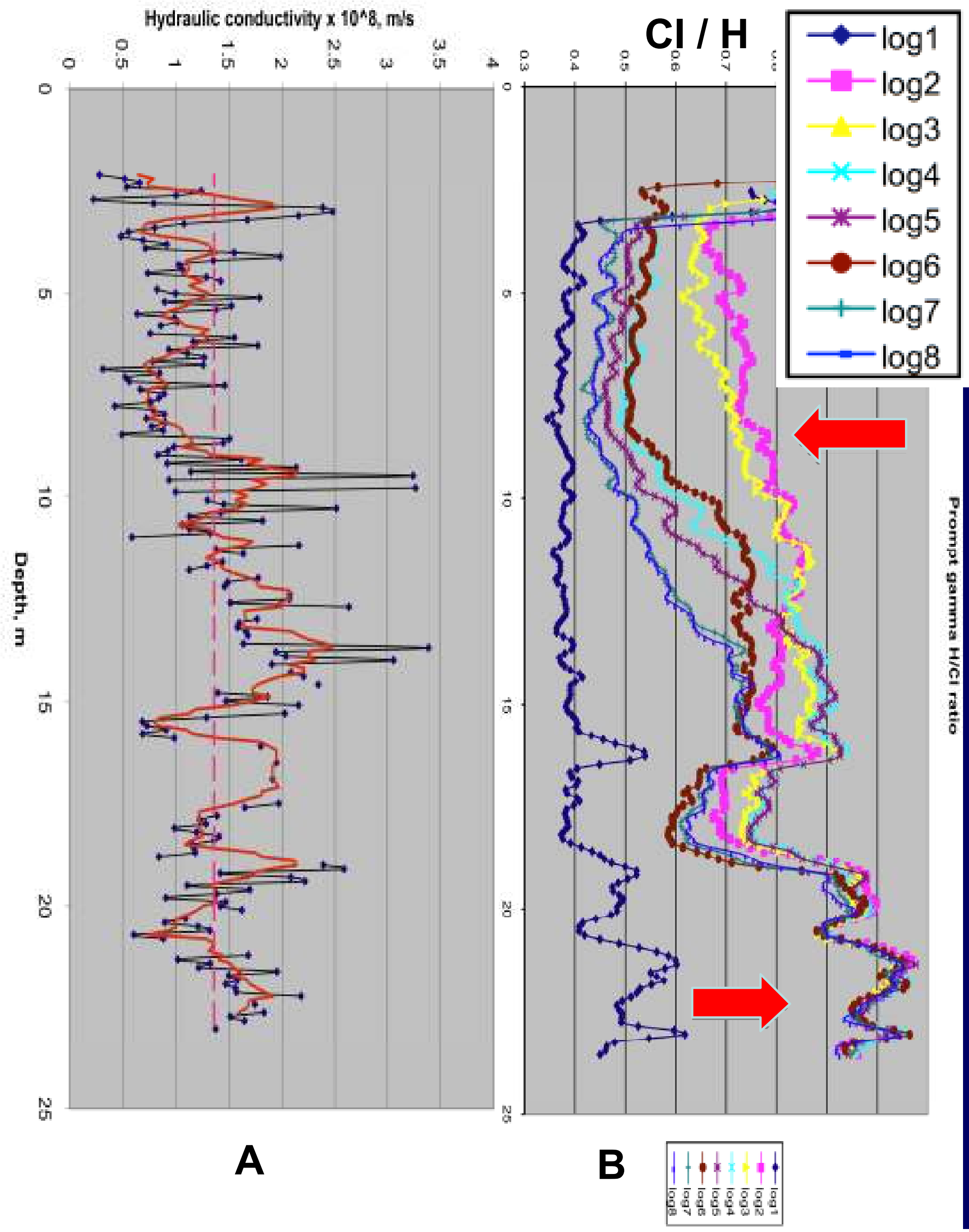
Hydraulic Conductivity Calculation

Principle Applied

Activated gamma emissions at low energies are attenuated more by transmission through rock & water than high energies

Hence changes in the ratio of the tracer emission is a function of the distance the tracer has moved away from the injection bore ie Cl 1.95 / 6.1 MeV

To calculate Hydraulic Conductivity a NaCl or KCl tracer is injected and relative distance moved under an applied hydraulic gradient is measured



A

Hydraulic conductivity calculated from distance NaCl tracer moves beyond borehole

B

Sequential PGNAA log of tracer movement

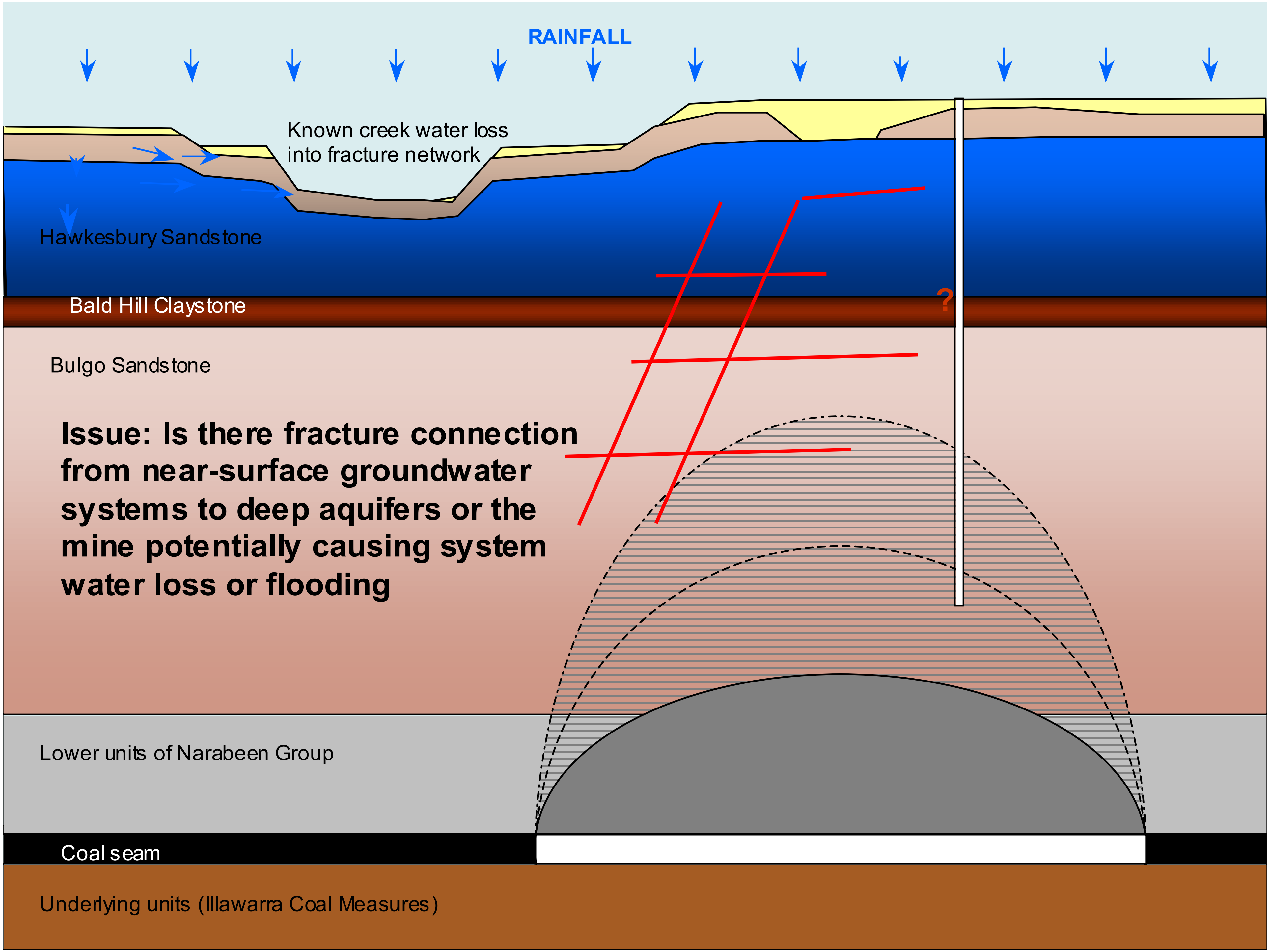
Log 1 = no tracer

Log 2 = pink

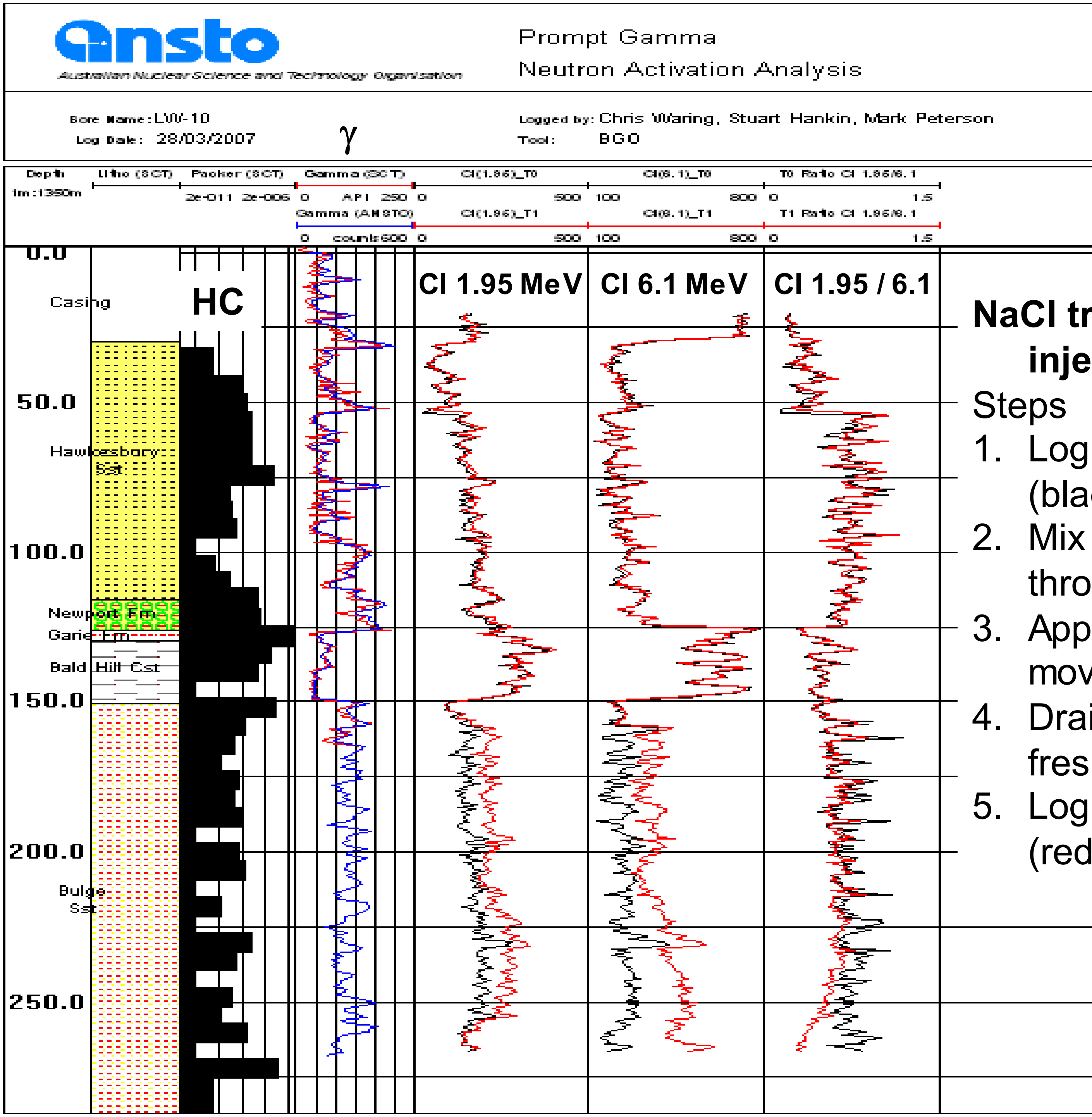
Apparently less tracer in top of borehole with time

Dense NaCl tracer moving away from borehole at the base

Lowers SWL, causes flow into borehole at top


RAINFALL
Known creek water loss
into fracture network
Hawkesbury Sandstone
?
Bald Hill Claystone
Bulgo Sandstone
Issue: Is there fracture connection from near-surface groundwater systems to deep aquifers or the mine potentially causing system water loss or flooding
Lower units of Narabeen Group
Coal seam
Underlying units (Illawarra Coal Measures)

Borehole into goaf leaking at base



NaCl tracer injection & migration

Steps

1. Log bore with PGNAA (black)
2. Mix 5% NaCl tracer through bore
3. Apply P (head) to tracer to move tracer into rock
4. Drain 2x bore volume freshwater from top of bore
5. Log bore with PGNAA (red)

Conclusion

Porosity and hydraulic conductivity

- PGNAA borehole logging is capable of detecting subtle variations in relative porosity.
- A new method for measuring high spatial resolution increments of hydraulic conductivity in a borehole is described and demonstrated in practice.

Vertical hydraulic connection

- Sequential tracer injection and PGNAA logging can identify induced advective circulation cells in sandstone adjacent to a borehole.
- Establishing vertical hydraulic connection can be very useful in assessing the impact of longwall mining on groundwater hydrology.