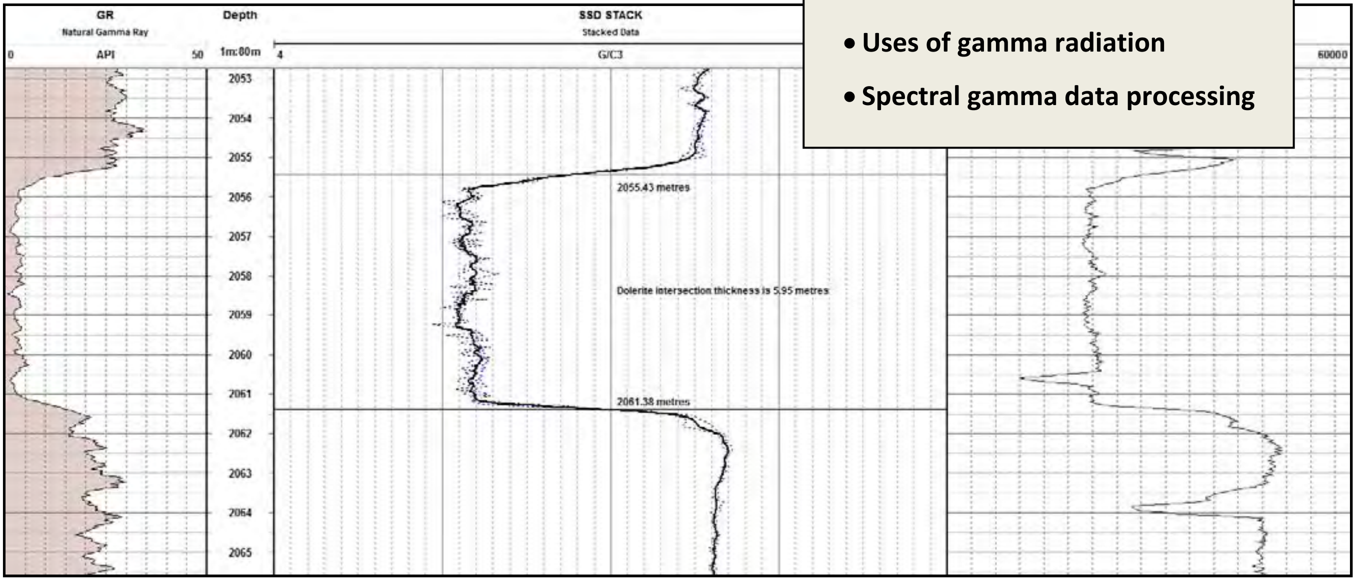
Issue 31 – September 2018

WIRELINE WORKSHOP

A BIMONTHLY BULLETIN FOR WIRELINE LOGGERS AND GEOSCIENTISTS ENGAGED IN MINING AND MINERAL EXPLORATION

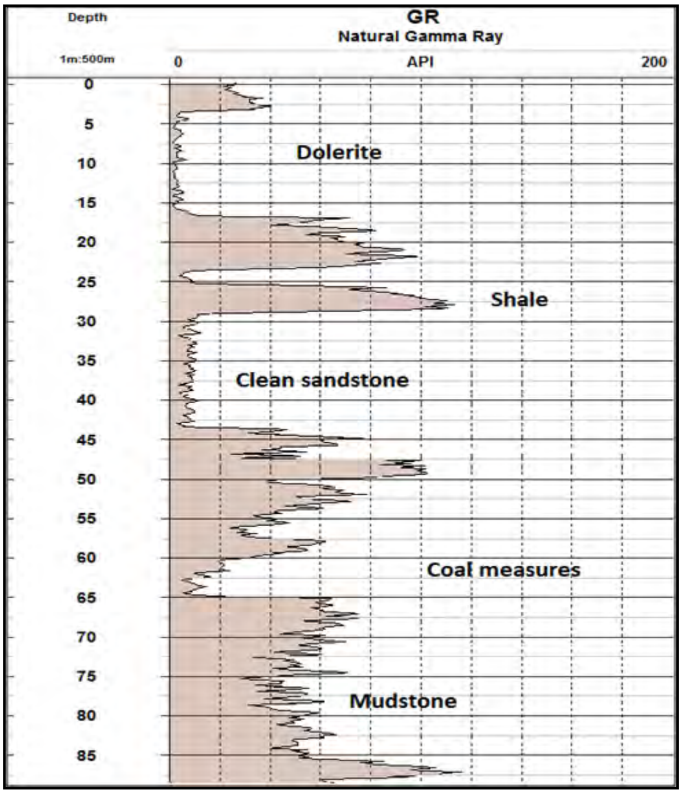
- What is radiation?
- Uses of gamma radiation
- Spectral gamma data processing



A long-reach horizontal borehole log describing a dolerite intersection through drill pipe

1. Gamma radiation - we mineral loggers use it a lot

One of the first things we do when we join a mineral logging company, is to learn about radiation safety. The logger employs a man made isotope of Caesium to measure density. Density is an important measurement, especially in the coal basin. But there are lots of other uses of radiation, both man-made and natural, that add to our understanding of the formation and, in some cases, allow us to measure the grade of an ore body.



Natural Gamma

The log on the right describes the formation in terms of total natural gamma radiation. The log may be calibrated to allow precision and, with some allowance for borehole diameter and fluid density effects, accuracy.

The industry standard unit for the gamma log is API or, more correctly perhaps GAPI. This is a unit of radiation based on the American Petroleum Institute's test pits in Houston, Texas, where an artificially made concrete block has a radiation level of twice that of a typical shale.

In the absence of uranium, shale normally exhibits the highest counts in a gamma log because it is clay rich and, importantly for lithological analysis, clay is the source of most natural radiation. In clastic sediments, the gamma log is a measure of clay fraction. So, on the right we can see a layer of "clean" sandstone. That means very low clay fraction.

Before going further we should study a bit of radiation theory. This is a practical guide for the logger.

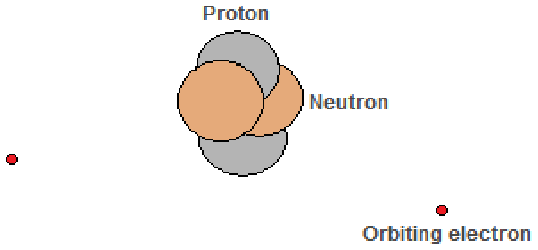
What every logger (and many a geologist) needs to know

The wireline logging engineer employs radioactive sources and equipment that detects gamma rays (natural and induced) and neutrons. It is important for him to understand the various principles of measurement so that he can find the job more fulfilling and offer informed opinions to the client when required. Before studying individual wireline log measurements he should first have a basic understanding of the nature of radiation. This is a simple guide which is not for the scientist but is, hopefully, both easy to understand and to remember.

The atom

The atom is the tiny building block of all matter. It is really small. If you placed atoms in a line, you could fit two hundred million of them in one centimetre. The atom has three components:

- Positively charge protons
- Neutrons with no electric charge
- Negatively charged electrons



The protons and neutrons (called nucleons) combine to form the core or **nucleus** of the atom. The electron is tiny. Its diameter is 1836 times smaller than a proton which is just slightly smaller than a neutron.

The picture on the right shows a helium atom. The densely packed nucleus is at the centre and the electrons are orbiting, some distance away. Actually, the diagram is misleading. The diameter of the central nucleus is (typically) ten thousand times smaller than the diameter of the atom as a whole.

So the electrons are spread out and have different orbits called shells. If the nucleus were the size of a golf ball, the nearest electron (orbiting in the inner shell) would be about a kilometre away. In complex atoms with lots of electrons, there are multiple shells. In our analogy, the second shell would be four kilometres away and the third shell ten kilometres away and so on.

The logger is interested in electron density.

So the atom is not a pile of bricks, it is a group of tiny particles held together, in space, by electro-magnetic energy. There is a lot of ‘inner space’. If you assembled the six billion people that live on Earth and took away the inner space of their atoms, you could fit the whole lot onto a teaspoon. That dense blob of humanity would weigh about three hundred million tonnes.

Atomic number and atomic weight

The helium atom has two positively charged protons. Because the atom prefers a neutral electrical state overall, it requires two negatively charged electrons to balance its charge. There are also two neutrons with no charge. These can be thought of a protons and electron squidged together as one particle.

So why do we have neutrons? The protons, all having a similar electric charge, repel each other by the effect of the electro-magnetic force. They are held together in the nucleus by the counter (attracting) effect of the strong nuclear force. This force is stronger than the electro-magnetic force but has a smaller range. The neutrons are there to hold the atom together. They add to the overall binding effect of the strong nuclear force but exert no electro-magnetic repulsion. Because the repulsive force has a longer range, bigger atoms need extra neutrons to counter its effect and to provide stability.

Sooner or later, all unstable atoms must disintegrate.

The various chemical elements are defined by the composition of the atom. The **Atomic Number** (Z)of an element is the number of protons in its atom. This is usually the same as the number of electrons. The number of electrons can vary temporarily. If the atom gains or loses an electron it is called an **ion** and will become negatively or positively charged. Its atomic number will not change.

The **Atomic Weight** (A) of an atom is the total weight (mass) of all the protons, neutrons and electrons. A silicon atom has a mass of 28.0855 g/mols. Since it bears atomic number 14 we can predict that it has 14 proton/electron pairs (to balance its charge) and14 neutrons to help it hold together. Each element may have more than one **isotope**, atoms with the same atomic number but different numbers of neutrons.

The periodic table

An abbreviated list of elements (most common isotopes)				
Z	**Name**	**Chemical series**	**Mass (g/mol)**	**Comment**
Common hydrogen has just one nucleon, a proton (it requires no neutron)				
1	Hydrogen	Non-metal	1.0079	Z/A = 1
Most rock-forming elements, between 2 and 20, have Z/A ratios close to 0.5				
2	Helium	Noble gas	4.0026	Z/A = 0.5
4	Beryllium	Alkaline earth metal	9.0121	1 extra neutron
6	Carbon	Non-metal	12.0107	Z/A = 0.5
8	Oxygen	Non-metal	15.9994	Z/A = 0.5
11	Sodium	Alkali metal	22.9897	1 extra neutron
12	Magnesium	Alkaline earth metal	24.3050	Z/A = 0.5
13	Aluminium	Poor metal	26.9815	1 extra neutron
14	Silicon	Metalloid	28.0855	Z/A = 0.5
17	Chlorine	Halogen	35.4530	1 extra neutron
19	Potassium	Alkali metal	39.0983	1 extra neutron
20	Calcium	Alkaline earth metal	40.0780	Z/A = 0.5
There is a significant increase in (extra) neutron count above atomic number 20				
21	Scandium	Transition metal	44.9559	3 extra neutrons
26	Iron	Transition metal	55.8450	4 extra neutrons
28	Nickel	Transition metal	58.6934	3 extra neutrons
29	Copper	Transition metal	63.5460	6 extra neutrons
30	Zinc	Transition metal	65.3800	5 extra neutrons

The ‘Periodic Table’ above is abbreviated to concentrate on the major rock-forming elements. The first thing to notice is that hydrogen, the smallest atom, has an atomic weight close to just 1. This indicates that it has no neutron, which is indeed the case. It does not need a neutron as there is no second proton pushing the atom apart. It must be the most stable atom.

The second thing to notice is that, for all of the major rock-forming elements (silicon, magnesium, aluminium, calcium and oxygen), the Z/A ratio, the proportion of protons (Z) nucleons or atomic mass (A) is close to 0.5.

Wireline loggers have a clever way of detecting **electrons** in the rock formation. This allows them to determine the abundance of protons therein which, because there are a similar number of neutrons, is roughly related to bulk density. So variations in chemistry do not affect the estimation of density.

If the Z/A ratio is 0.5, electron density is proportional to bulk density.

The third thing to notice, in the Periodic Table, is that the Z/A=0.5 rule changes at about atomic number 20. The elements that include the base metals have atoms that are large enough to require a few extra neutrons to hold them together or stabilise them. Electron density will not be proportional to bulk density.

Radiation

If an atom is unstable sooner or later it will disintegrate (decay). The very large atoms of elements above 82 in the Periodic Table have no stable isotopes at all. In a sense, they are just too big and so they are unstable.

An abbreviated list of elements (most common isotopes)

Z	Name	Chemical series	Mass(g/mol)	Comment
Common hydrogen has just one nucleon, a proton (it requires no neutron)				
1	Hydrogen	Non-metal	1.008	Z/A = 1
Most rock-forming elements, between 2 and 20, have Z/A ratios close to 0.5				
4	Beryllium	Alkaline earth metal	9.012	4 protons and 5 neutrons
14	Silicon	Metalloid	28.085	Z/A = 0.5
17	Chlorine	Halogen	35.453	17 protons and 18 neutrons
There is a significant increase in (extra) neutron count above atomic number 20				
26	Iron	Transition metal	55.845	26 protons and 30 neutrons
50	Tin	Poor metal	118.710	
55	Caesium	Alkali metal	132.905	Caesium Cs^{133} has 55 protons and 78 neutrons
79	Gold	Transition metal	196.966	
80	Mercury	Transition metal	200.590	
81	Thallium	Poor metal	204.383	
82	Lead	Poor metal	207.200	Lead Pb^{207} has 82 protons and 125 neutrons
The elements above atomic number 82 have no stable isotopes				
83	Bismuth	Poor metal	208.980	
84	Polonium	Metalloid	208.982	
86	Radon	Noble gas	222.017	
88	Radium	Alkaline earth metal	226.025	Radium Ra^{226} has 88 protons and 138 neutrons
90	Thorium	Actinide	232.038	
91	Protactinium	Actinide	231.036	
92	Uranium	Actinide	238.029	Uranium U^{238} has 92 protons and 146 neutrons
95	Americium	Actinide	243.061	
98	Californium	Actinide	251.080	

All elements have more than one isotope and at least one is unstable. This means that all elements have at least one radioactive isotope. Even hydrogen has a (very uncommon) radioactive isotope; H^3 has one proton, two neutrons and a 'half-life' of approximately 12 years.

The term **half-life** is used because the total radioactive life of a sample of an unstable isotope cannot be measured. Radioactive **decay** occurs randomly and is unpredictable so, in an isotope with a half-life of 20 years, some atoms will take 500 years to decay. The half-life is the average time it takes for half of the atoms to decay.

What does decay mean? It is a disintegration resulting from the atom having wrong number of neutrons, or having too many neutrons (too much energy, too much mass or both). The nucleus of such an unstable atom is unbalanced or just too large to maintain its current state indefinitely. It must decay to a smaller size by releasing some of its mass.This is done by the spontaneous emission of a particle, either alpha or beta decay.

Alpha decay kicks out the equivalent of a helium atom; two neutrons and two protons, so the atom changes to another elemental state, two steps lower down (up the list of) the Periodic Table.

Beta decay (typically) kicks out an electron from the nucleus, changing a neutron into a proton and moving the atom to a new elemental state further up the Periodic Table (down the list). This might be a transient stage for the very large elemental atoms because, ultimately, Alpha decay will move them in the direction of stable lead.

So that's it, in a nutshell; gamma radiation is excess energy released by an atom immediately after it decays to a smaller size.

The reduction in mass after Alpha decay means that an atom requires less energy to maintain its new shape. To correct this situation, a burst of electro-magnetic energy with no mass is released from the atom. It is a photon, known as a **gamma ray**. This is radiation resulting from atomic decay and it is a universal phenomenon.

Natural gamma radiation

There are three naturally occurring sources of radiation:

- Potassium (K^{40})
- Uranium (U^{238} and U^{235})
- Thorium (Th^{232})

Isotopes are variants of a particular chemical element which differ in neutron number. All isotopes of a given element have the same number of protons in each atom (Wikipedia).

Uranium is number 92 on the Periodic Table, so it cannot decay to the nearest stable element, lead (see table), in one step. It takes fourteen steps creating new **daughter** isotopes which all have different half-lives.The half-lives vary from billions of years to a few micro-seconds.

This all means that, wherever you find uranium deposits, you would normally expect to find all the daughter elements in the same place although because uranium is soluble and can be transported by water, that is not always the case.

It also means that, given the age of the Earth, the only natural sources of radiation that are likely to be around are those with very long half lives; potassium, uranium and thorium and, of course, their progeny.

Back to clay

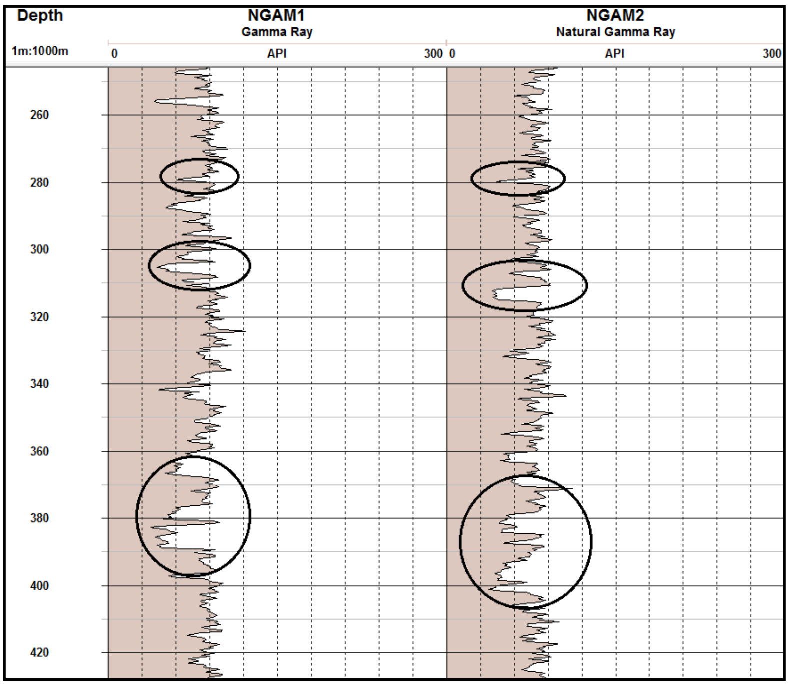
From the logger's perspective, clay has two important characteristics; it contains a lot of water (H and O) and it is radioactive. Actually, clay, in terms of its radioactivity, is a complex subject. The radiation is dominated by potassium whose presence, like hydrogen and oxygen, is not all random but part of the molecular structure, of the mica group of clays in particular. In this case is referred to as structural potassium.

Surfaces within the clay lattice are usually negatively charged so they tend to trap positively charged ions (cations), including uranium and thorium cations. So clay is radioactive and the radioactivity of a clastic sedimentary formation depends on its clay content.

Any rock that was previously part of a plant or an animal, coal and limestone for instance, should exhibit very low gamma ray counts.

The gamma log is largely unperturbed by borehole conditions. It is used as a depth reference (many logging tools carry a gamma detector so that separate runs may be perfectly aligned in terms of depth) and is an excellent **correlation** tool.

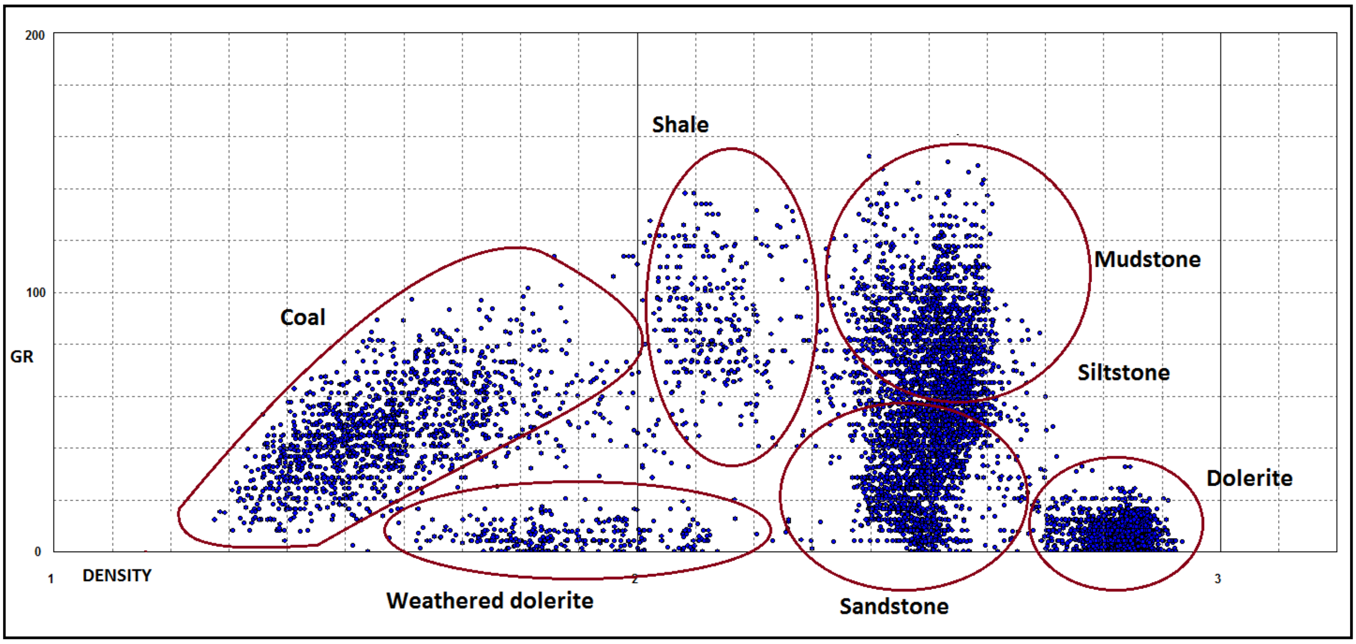
Quite subtle correlation may be determined with some pattern recognition skills.



Cross hole correlation using gamma logs

The log on the right illustrates a rather difficult pattern to recognise. It is most often much easier than this, particularly if the boreholes are closely spaced.

In some cases the gamma log is not, on its own, diagnostic of rock type. Coal, sandstone, limestone, halite and dolerite, to name a few, all exhibit low gamma counts but combination with density can work rather well.



A coalfield data set with gamma and density cross-plotted

Gamma ray logs are statistical in nature. It is very important to run the gamma sonde slowly to allow sufficient time per depth unit for averaging the log. A larger or denser crystal will also improve statistics.

The gamma log is most often used **qualitatively**; ever present on borehole logs, usually in track 1 (the far left track), as a basic lithological indicator and depth control.

The logs are used **quantitatively** in uranium and potash projects.

In the **uranium** case, the logger is measuring total gamma that comprises counts from all the daughter isotopes. If the uranium is in or close to equillibrium, the total gamma count is proportional to the U grade and can be calibrated as such.

Counts are high and the effect of potassium and thorium contributions can be ignored.

There are issues with dead time losses and the effect of the ore body's very high Z (lots of electrons) moderating its own radioactivity but these factors affect only the highest grades and can be corrected when necessary.

Potash is a bit easier because, as a result of selective deposition among the evaporite minerals, the target contains potassium only, no uranium or thorium. So, again, total gamma will do the job. Count rates are not high so there is no dead time loss or Z effect to contend with. Calibration using a reference well and laboratory analysis is straightforward if there is sufficient data.

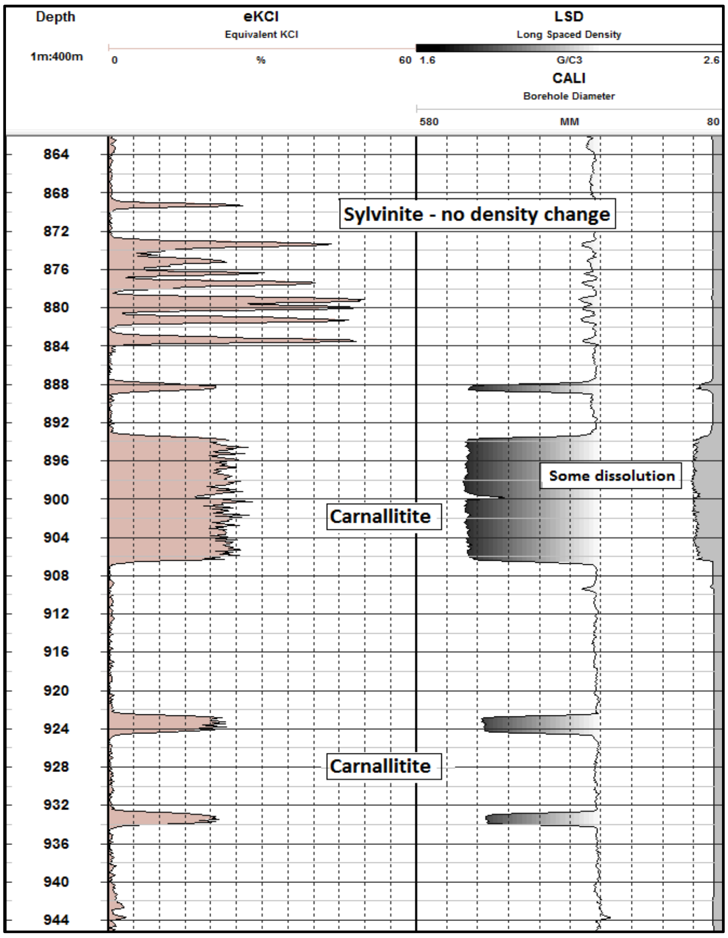
Evaporite salts form an impermeable cap and are often drilled through in the search for oil. This logger has been asked to analyse oilfield gamma logs on several occasions. The oil logger has faithfully recorded total gamma through the salts but has not taken much notice of the potash beds except for that annoying bischofite that dissolves into a huge cave.

Two things should be noted. Firstly, the oilfield logger does not run a simple gamma sonde. His device is part of a triple or quad combo with a 1Ci Cs137 source used to log density. There is always a baseline shift of the natural gamma log as a result of pollution from the density logger. It's easy to see in the halite zones which should be close to zero.

Secondly, the oil logger does not, or did not, always compensate natural gamma for borehole diameter and mud weight. It is essential to drill and log a reference borehole to recalibrate the API data. The effect of these variables is quite large.

Although bischofite dissolves readily, it is not usually the target. Borehole conditions in carnallitite and sylvinite are reasonable and good respectively. On one occasion, a client required a density log but did not want to pay for the extra tooling. The solution was to send a simple trisonde source and a brass spacer to allow the GR sondes to be converted to density sondes.

The log on the right shows the result; a perfectly



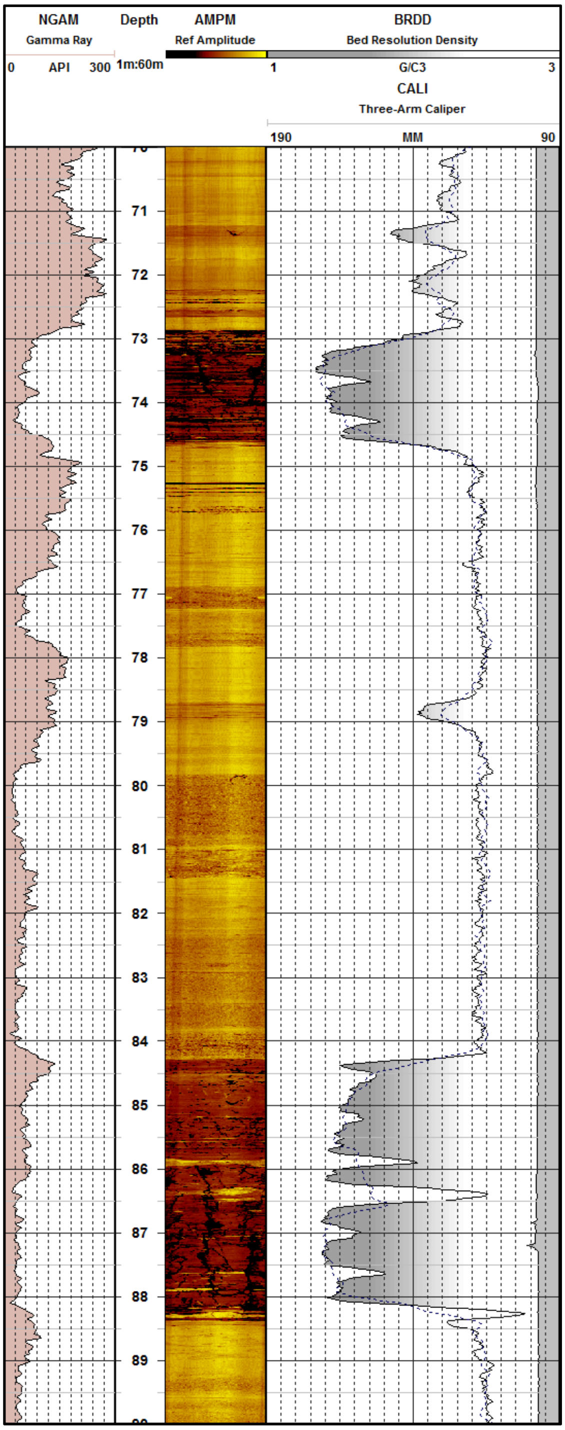
serviceable density log (LSD) at reduced cost. The long spacing helped to minimise the effect of the dissolution in carnallitite (check the caliper log, far right).

Gamma-gamma density logs

The density sonde is, basically, a gamma sonde with a radioactive source attached. Add some collimation, a second or third detector, a calibration system and some compensation for borehole diameter, mud weight, natural gamma and the Z effect (H) in coal and you have the very best mineral density measurement.

Density logs are used to

- Determine depth and thickness of coal deposits
- Provide an indication of coal quality, ash and calorific values (empirically)
- Log iron ore depth, thickness and grade
- Log general lithology and porosity (SST, LST, DOL)
- Provide a component for formation elasticity equations
- Provide a component for acoustic impedance logs



Natural gamma ray, depth column, acoustic amplitude image, dual density (shaded) and caliper

Beyond depth and thickness, the density measurement is difficult to get right. Actually, it is never right but it can be accurate within a reasonable tolerance.

There might be a variable formation chemistry to deal with but the main problem relates to the need for high resolution versus the requirement to sample a representative volume and the difficulty in moderating borehole wall effects.

The higher the resolution the smaller the sample volume and the larger the perturbing effect of borehole irregularities.

In the example on the right, the borehole has been diamond cored at 76mm diameter and is very straight. A vertical resolution of 15cm can be achieved without loss of measurement fidelity.

15cm is usually considered to be the highest resolution allowable using a Caesium source. The spacing can be reduced in dense rocks but, generally, to avoid ambiguity, manufacturers stick to a 14 or 15 cm spacing. They can use a lower energy americium source for the highest resolution, about 8cm, but the cost in terms of borehole wall effects can be very damaging. It is always a trade off.

In larger percussion-drilled holes a minor loss of fidelity has to be accepted unless some form of long and short spaced log combination is available.

Alpha-processing combines the large volume log of LSD with the high resolution of SSD or BRD. It is considered to be the best option in larger boreholes but relies on excellent tool characterisation and well calibrated component logs.

One great advantage of radiation logs, natural gamma and density, is that they can be run through steel pipe or casing. The picture at the top of page 15 shows an angled hole being drilled to intersect a coal seam, eventually running horizontal. A gamma / density sonde is pumped to the end of the hole, sometimes over 2 kilometres away and then logged out. The object is to detect any intersecting dolerites...low gamma, high density.

Both natural gamma and density logs are commonly used in mineral logging. There are occasions when the logger's client would like to have a log of the components of the total gamma log. These are Potassium, Uranium and Thorium.

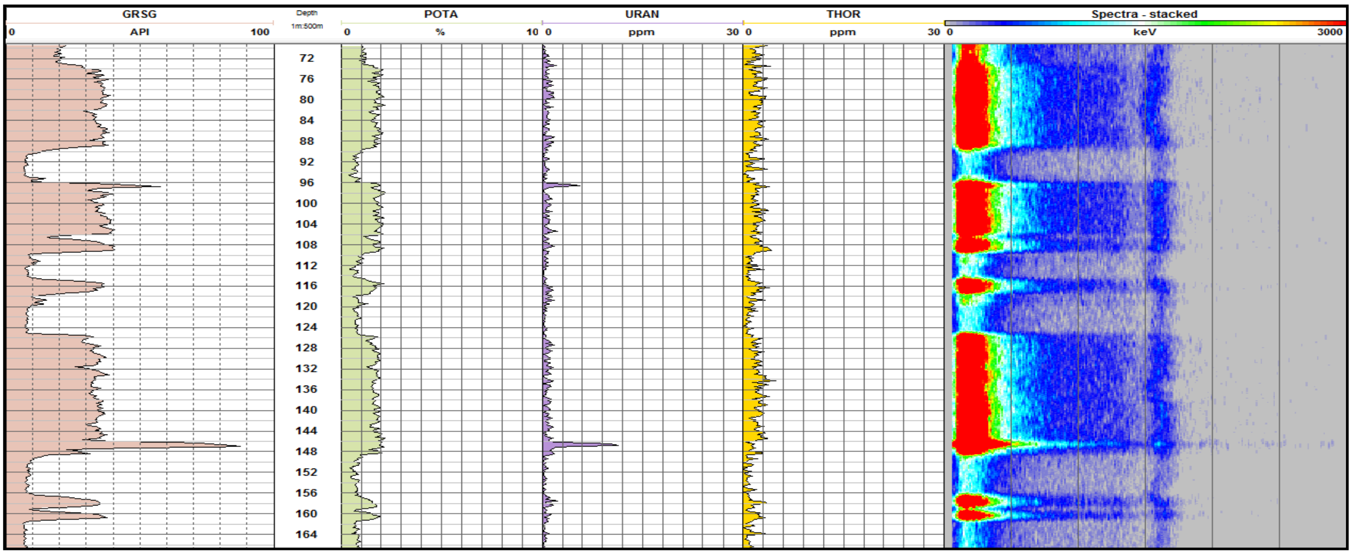
The full energy spectrum is recorded at 5 or 10 centimetre depth intervals. The three common isotopes of the K,U,Th elements, or their representative progeny (for U it is ^{214}Bi), are windowed in terms of a relevant energy range and counted.^{40}K does not use a surrogate.

Because of Compton Scattering, the energy moderation caused by collisions with electrons in the formation, the lower energy windows will include some gamma rays that originated at higher energies. Only the highest energy window, that focussed on Thallium (^{208}Tl representing Th), at about 2.6MeV, allows the counting of Tl counts only.

So if the spectrum is plotted from 0 energy left and the maximum, usually 3MeV on the right, there is an unseen cloud of decaying gamma rays moving past each window from the high energy to low energy end of the spectrum...from right to left. The spectrum is always higher at the left end of the graphic display (see page 10).

A process of calibrated stripping ratios is required to separate the measurements of K, U and Th. So calibration and stripping is one issue. Temperature drift is another. The whole spectrum will move as the scintillation crystal warms up when the sonde is lowered into a borehole.

Real time logging of K, U and Th for lithology logging and clay typing studies relies on a caesium locking source fitted to the sonde. Its known energy peak offers a reference to correct lateral drift. That is an excellent solution for lithology logging. It cannot be used if there is a lot of uranium about because its peak is obscured by a nearby bismuth peak. The system cannot lock on.



A spectral gamma log

Another problem for the poor old spectral gamma sonde is that it must be run very slowly. The sodium iodide crystal size limited by the small diameter of mineral boreholes. Denser materials are available to improve counting rates but these are either more sensitive to temperature or generate their own gamma signal.

A good spectral gamma log can be extremely useful to the geologist. The advice is, run the tool as slowly as possible and consider the following section on spectral gamma log processing.

2. Spectral Gamma Processing in WellCAD

A Guest article by Timo Korth of ALT

Spectral Gamma Ray (SGR) borehole logging is widely used to obtain lithological information from boreholes and plays a key role in oil & gas exploration and mining. To convert spectral information into radionuclide concentrations WellCAD offers two different processing approaches - **Windows Stripping** and **Full Spectrum Analysis**.

Windows Stripping

This operation uses the counts collected in three or more windows overlaying the position of the ^{40}K and the high energy peaks of ^{238}U and ^{232}Th. The derived source strength in cps can be converted to radionuclide concentration using a calibration model specifically developed for the logging tool.

Corrections for spectrum drift and borehole environment (e.g. diameter, fluid type and casing) should not be neglected.

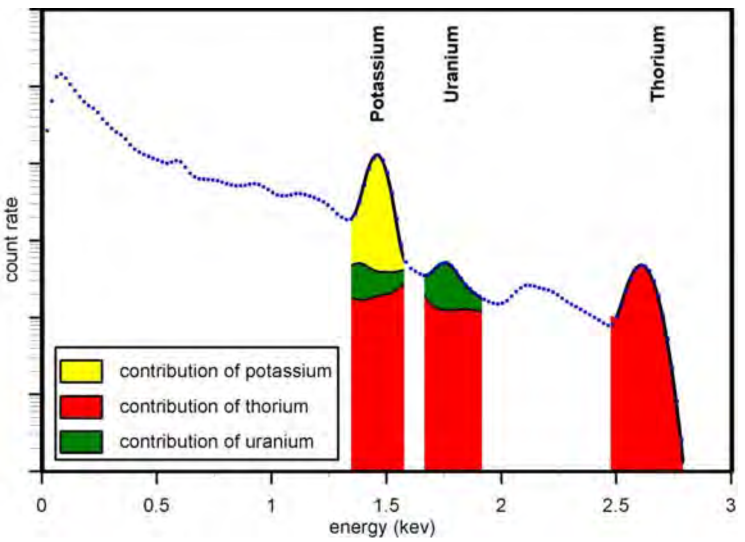


Figure 1 - Windows Stripping of gamma ray spectrum (blue dots)

Full Spectrum Analysis

While the Windows Stripping method is finding the activity of nuclides by summing up the counts in discrete intervals of the spectrum, the Full Spectrum Analysis (FSA) takes (almost) the entire spectrum into account. FSA describes the measured spectrum as the sum of “Standard Spectra”.

The fitting procedure yields the multiplication factors needed to reconstruct the measured spectrum from the standard spectra.

These multipliers equal the actual concentrations of the radionuclides that led to the measured spectrum (see *Hendriks et al, Full-spectrum analysis of natural γ-ray spectra, Journal of Environmental Radioactivity, 2001*).

The standard spectra are derived from separate calibration measurements for each radionuclide.

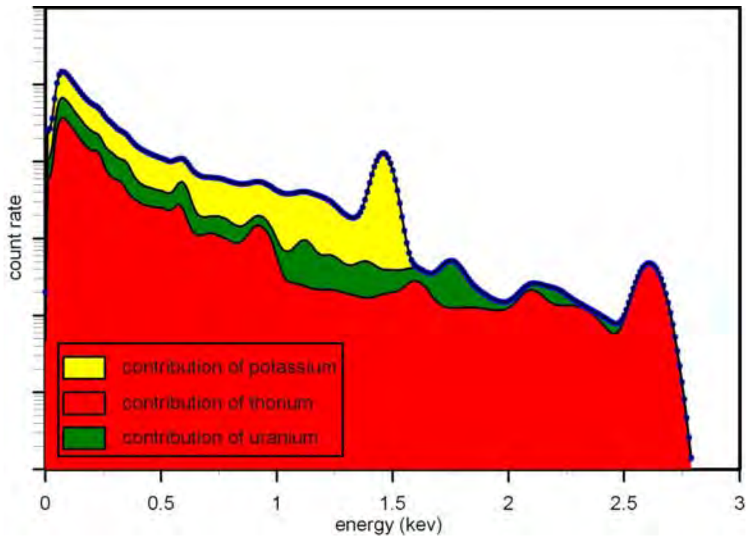


Figure 2 - Full Spectrum Analysis (FSA)

Figure 1 and **2** illustrate both methods. The Windows Stripping method (figure 1) uses only parts of the measured spectrum. Stripping factors derived from a calibration model account for the contribution of radiation from the different radionuclides in the same energy window (resp. energy peak).

The FSA (figure 2) approximates the entire measured spectrum by a composition of the contributions of ^{40}K, ^{238}U and ^{232}Th derived from standard spectra fitting.

In WellCAD spectral data is stored in the FWS Log type and is best displayed using the Wiggle or VDL display styles (see **figure 3**).

The **Process**>**Common**>**Total & Spectral Gamma** menu offers all processes related to spectral data, including the above-mentioned analysis methods.

No add-on module is necessary to access these processes. This article will focus on the application of the Windows Stripping and Full Spectrum Analysis processes.

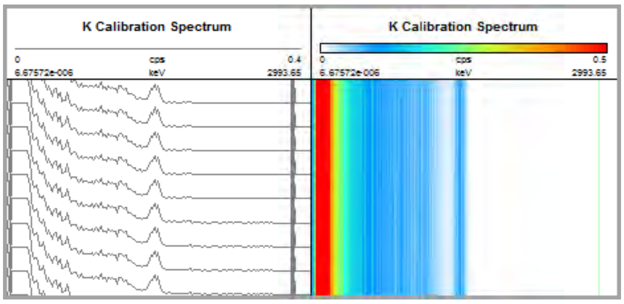


Figure 3 - FWS Log used to store and display spectral data in WellCAD

Processing SGR data in WellCAD using the FSA method

The use of the Full Spectrum Analysis requires a logging tool specific calibration file containing the standard spectra and information about the spectrum stabilization of the detector system. The FSA method implemented in WellCAD has been developed by Medusa Sensing (*www.medusa-sensing.com*) and takes care about spectrum stabilization (drift correction), computation of the nuclide concentrations, their uncertainties and corrections for the borehole environment. Calibration files supported by the process in WellCAD are available from the tool vendors or Medusa-Sensing. WellCAD enabled calibration files can be identified by the file extension *. mcf.

After importing your spectral data into WellCAD open the **Process**>**Common**>**Total & Spectral Gamma**menu and select the **Full Spectrum Analysis…** option. The Medusa Spectral Gamma Process dialog box opens (**figure 4**).

Select the FWS log containing the spectrum data. It should be in counts per channel (1).

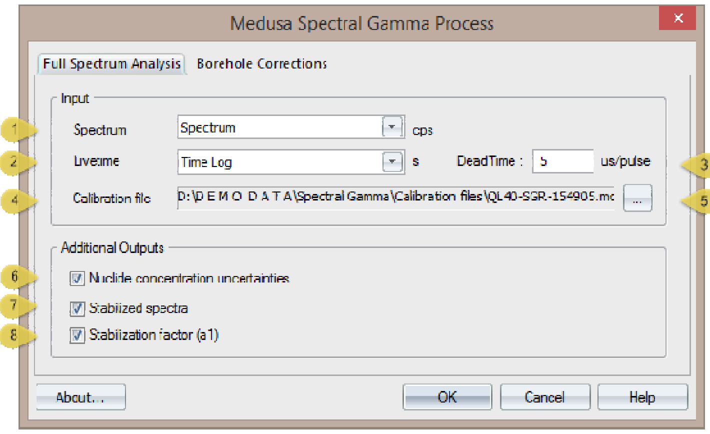
Enter the sample time of your logging system (time for one measurement cycle) or select a corresponding data channel (2). Specify the Dead Time (3) of the detection system.

Click the options button (5) to load the calibration file corresponding to the logging tool that recorded the data. A separate dialog box opens (figure 5).

Select the calibration file from the list (set the path to the folder containing the calibration files if no file is displayed). An info box shows the detector ID (e.g. tool serial number), calibration date and information about the standard spectra contained).

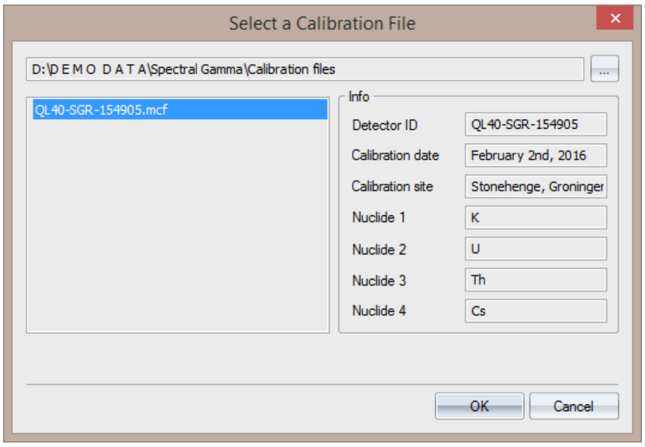
Click on **OK** to revert back to the FSA parameters.

Ensure the correct calibration file shows up in the corresponding box (4). The default output of the FSA will be the nuclide concentrations of K, U and Th in units set in the calibration file.



Spectrum: Spectrum cps
Livetime: Time Log s DeadTime : 5 us/pulse
Calibration file: D:\D E M O D A T A\Spectral Gamma\Calibration files\QL40-SGR-154905.mc
☑ Nuclide concentration uncertainties
☑ Stabilized spectra
☑ Stabilization factor (a1)

Figure 4 - Parameter dialog box for the FSA



D:\D E M O D A T A\Spectral Gamma\Calibration files
QL40-SGR-154905.mcf

Detector ID	QL40-SGR-154905
Calibration date	February 2nd, 2016
Calibration site	Stonehenge, Groninger
Nuclide 1	K
Nuclide 2	U
Nuclide 3	Th
Nuclide 4	Cs

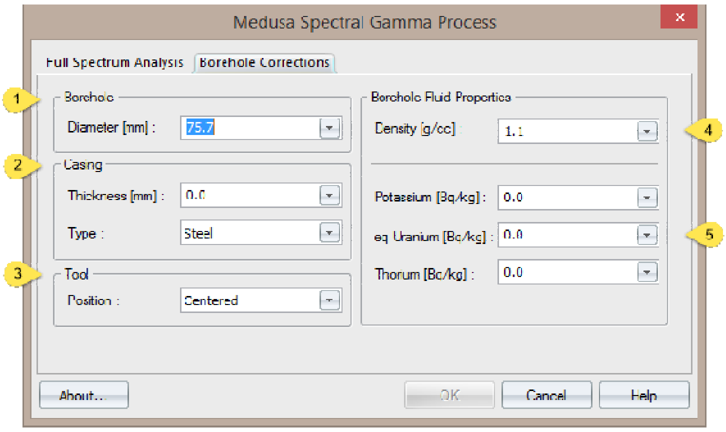
Figure 5 - Calibration file selection and info

If further standard spectra for additional nuclides (e.g. ^{137}Cs) are contained in the calibration file the corresponding concentrations will be output as well.

The user can enable additional outputs such as the concentration **uncertainties** (6). Besides an error curve for each nuclide concentration the user will get a Chi2 curve. Chi2 is a measure for the quality of the standard spectra fit to the measured spectrum. For a statistically perfect fit, the value for Chi2 should be close to 1. A larger Chi2 means a poor model fit while a Chi2 below 1 indicates the model is over-fitting the data.

Other additional outputs are the **stabilized spectrum** (7) and the stabilization factor named **a1** (8). Detector system and environmental factors (e.g. temperature) often cause the measured spectrum to drift. Peak positions from the measured spectrum would not correspond to peak positions of the standard spectra leading to poor fit results. Therefore, a spectrum stabilization algorithm is run prior to the fitting procedure. The algorithm uses data from the calibration file to find and adjust the measured peaks to a standard energy spectrum derived for the detector system. This results in a stabilized energy calibrated spectrum which will be used for the fitting procedure. With the Stabilized spectra option (7) checked the stabilized spectrum will be output as a new FWS log. The stabilization parameter a1 is a measure for the correction applied to the original spectrum. Please note that peaks from unknown radioactive substances in the spectrum and improper or outdated calibration (detection systems age over time) may lead to improper stabilization results.

Before commencing the FSA process the user should open the **Borehole Corrections** tab (**figure 6**) in the Medusa Spectral Gamma Process dialog box. Setting the correct parameters for borehole diameter (1), casing type and thickness (2), position of the logging tool in the borehole (3) and borehole fluid properties (density (4) and concentration of radioactive additives (5)) is advisable. Corrections will be applied to the derived radionuclide concentrations and output as an additional data channel (with a suffix "- Corr" in the log title).



Borehole
Diameter [mm] : 75.7
Casing
Thickness [mm] : 0.0
Type : Steel
Tool
Position : Centered
Borehole Fluid Properties
Density [g/cc] : 1.1
Potassium [Bq/kg] : 0.0
eq Uranium [Bq/kg] : 0.0
Thorium [Bq/kg] : 0.0

Figure 6 - FSA borehole correction parameters

Figure 7 shows an example of a data set processed using the FSA method. The differences between the uncorrected and corrected concentrations (for a water filled NQ borehole) are in the range of 5-10ppm for ^{238}U and < 1% for ^{40}K.

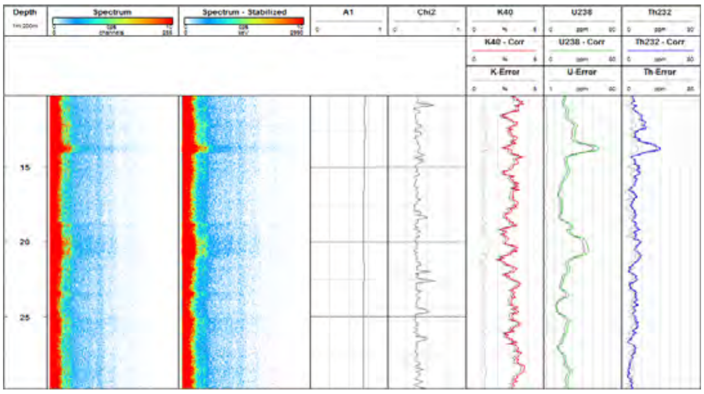


Figure 7 – Sample of a data set processed with the FSA method

Since WellCAD version5.2 the constraint that an FWS log type requires a constant depth sample step has been removed. As a consequence, logs derived from data in an FWS log with a non-constant sample step are output as a Mud log. If required you can easily convert multiple selected Mud logs into Well logs using the **Convert Log To** process from the **Edit** menu.

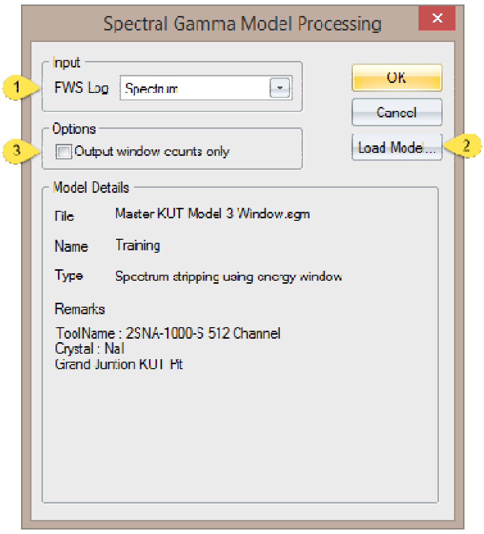
Processing SGR data in WellCAD using the Windows Stripping method

When clicking on the **Windows Stripping** option in the **Process**>**Common**>**Total & Spectral Gamma** menu a simple dialog box opens (**figure 8**). The only options provided are the selection of the input spectra (1) from a FWS log, the loading of a calibration model (2) and the option to output window counts only (3).

The input spectra can be energy calibrated or channel based. It depends on the spectra and windows settings used in the calibration model.

Corrections for spectrum drift (e.g. using the Drift Correction process) or borehole environment (e.g. using the Borehole Condition Corrections process and correction charts supplied by the tool vendor) should be applied prior to running the Windows Stripping process.

The calibration file (*.SGM) is different from the **Medusa** calibration required for the FSA and can be created in WellCAD by using the **Window Based Model** option from the same menu.



Spectral Gamma Model Processing

Input

FWS Log: Spectrum

Options

☐ Output window counts only

Model Details

File: Master KUT Model 3 Window.sgm

Name: Training

Type: Spectrum stripping using energy window

Remarks

ToolName : 2SNA-1000-S 512 Channel
Crystal : NaI
Grand Juntion KUT Pit

Figure 8 - Windows Stripping dialog box

The steps to create such a model are explained below. If a model has been loaded details such as the detector system ID and used calibration pit are shown in a dedicated part of the dialog box.

If no calibration data is present the simplest model is one that contains the position of the stripping windows (i.e. energy windows) only. In this case the **Output window counts only** can be checked before proceeding. The resulting logs are the accumulated counts from each of the stripping windows.

If a complete calibration file was loaded the process outputs the radionuclide concentrations. No corrections for the borehole environment are supplied.

Creating a window-based model requires data from a calibration pit. Here the counts registered by the detector system of the logging tool in front of different radionuclide enriched zones of the test borehole are calibrated to the known concentrations of these radionuclides.

Figure 9 shows an example of the calibration spectra acquired in front of three different K, U and Th enriched zones. The high energy peaks significant for each reference zone are marked.

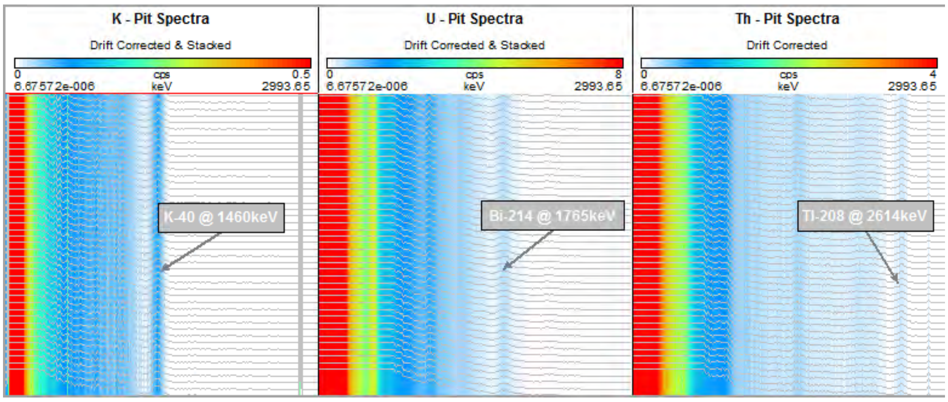
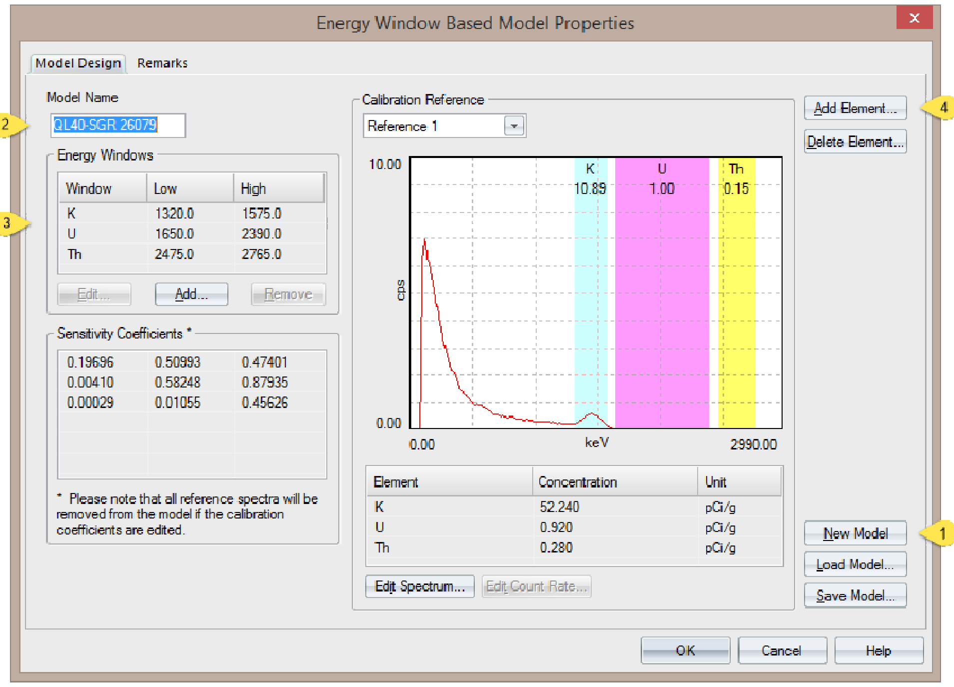


Figure 9 - Sample of static measurements in front of three different enriched calibration zones

The goal of the calibration is to center stripping windows on each of the reference peaks and relate the accumulated counts from each window to the mix of known radionuclide concentrations.

Have the calibration data open in a single borehole document and go to the **Process**>**Common**>**Total & Spectral Gamma**menu and click on **Window Based Model** to start the model building wizard.**Figure 10** shows an example of the user interface.

Please note that a full description of the model building process is given in the WellCAD manual and help system. To keep this article to a reasonable length we will only sketch the model building workflow.



Model Name: QL40-SGR 26079

Calibration Reference: Reference 1

K 10.89 | U 1.00 | Th 0.15

Energy Windows

Window	Low	High
K	1320.0	1575.0
U	1650.0	2390.0
Th	2475.0	2765.0

Sensitivity Coefficients *

0.19696	0.50993	0.47401
0.00410	0.58248	0.87935
0.00029	0.01055	0.45626

* Please note that all reference spectra will be removed from the model if the calibration coefficients are edited.

Element	Concentration	Unit
K	52.240	pCi/g
U	0.920	pCi/g
Th	0.280	pCi/g

Figure 10 - Stripping window model building dialog box

If the dialog box shows a previously loaded model, click on the **New Model** button (1). Define the stripping windows (2) next.

Click the **Add** button and select a default window from the drop-down list or define a new one.

If the reference spectra are energy calibrated set the low/high values for the windows in the same units (usually keV). Using a channel number if the reference spectra are not calibrated is possible.

Click on the **Add Element** button (4), select a radionuclide (e.g. K) and click on **Next** to choose a reference spectrum (figure 11 - 1) and enter the known concentration for this radionuclide (figure 11- 2). Click on **Finish** and start over with the next radionuclide (e.g. U).

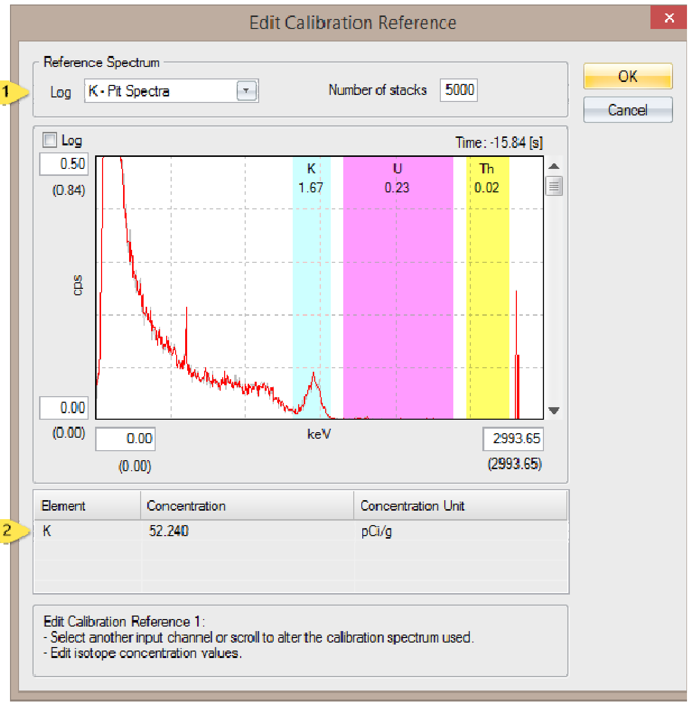
During the model building process, the user has to select for each enriched zone one reference spectrum and has to enter the known concentrations for all radionuclides present in that zone (i.e. enriched element and byproducts).

A complete calibration model for the radionuclides K, U and Th would consist of 9 calibration factors – from three reference zones each with known K, U, Th concentrations.

Do not forget to add calibration date and detector/tool ID in the **Remarks** tab before saving the model as *.SGM file.

To process the field data acquired with the same tool start the Windows Stripping process explained above.

Calibration is tool specific and should be repeated after a certain time since detector systems age.



Reference Spectrum: Log K - Pit Spectra; Number of stacks 5000

☐ Log; Time: -15.84 [s]

K 1.67 | U 0.23 | Th 0.02

Element	Concentration	Concentration Unit
K	52.240	pCi/g

Edit Calibration Reference 1:
- Select another input channel or scroll to alter the calibration spectrum used.
- Edit isotope concentration values.

Figure 11 – Select a reference spectrum and provide the known concentration

I hope you found this article useful. If you any questions related to the topics discussed in this article or would like to see other questions with regards to WellCAD addressed in the Wireline Bulletin, please feel free to contact Timo Korth (**support@alt.lu**).

Footnote...you have to intersect something!

It is worth remembering that a log is a record of events. A wireline log records changes in physical and chemical properties with depth or length of borehole. If holes are drilled horizontally there is normally no pattern of change, there is no intersection. The horizontal logs drilled in coal seams say little about coal quality. The borehole might be close to roof, floor or a parting.

They do measure dolerite dykes because these tend to intersect the sub horizontal coal seams close to vertically.

WIRELINE WORKSHOP

Marcus Chatfield – September 2018

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