A novel, advanced spectral-gamma tool for borehole logging systems

Medusa Sensing Tech Preview

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1.2	HL	16 September 2015	Included resolution results

Content

Introduction

Medusa Sensing has been a provider of scintillator-based gamma-ray detector calibration services for more than 10 years. Over the years, we’ve calibrated many different detector systems from several providers. These systems differ in make, crystal type, crystal size, data acquisition technology used, etc. etc.

Most of these tools were intended for spectral gamma-ray borehole logging. Such tools mostly comprise of a cylindrical NaI crystal, coupled to a (mu-metal shielded) photomultiplier tube and a readout by analog or (more recently) digital multichannel analyzer systems.

Over the years we have found a large variation in tool quality. In general we find that tools intended for the oil&gas industry have better quality than the equipment used in mining. A possible reason is that tools usie din the oil-industry are bigger, yielding a better radius/length ratio and contain more expensive electronics.

However, overlooking the variation in tool quality made us curious and motivated us to try and develop “typical mining” tool meeting oil&gas quality standards. In other words, to develop a small diameter gammaray sensor with high resolution and excellent linearity. The ingredients we needed for that are a proper scintillation crystal, high quality photomultplier tube, stabile and linear HV supply and a high-quality multichannel analyzer. And all this to fit within a tube of a bit over 1inch inner diameter. However, before getting to the results of our quest, let’s discuss a bit on the concept of *tool quality*.

A definition of tool quality

Before discussing our approach we should have a look at what we understand by *tool quality*. The “quality” of a spectral gammaray borehole tool is a governed by three factors:

1. Spectral resolution
2. Linearity of the tool
    a. gammaray energies
    b. temperature changes
3. Efficiency

The first two point, Spectral resolution and linearity, are the most important factors governing tool quality.

Spectral resolution, normally given as the fraction half-width-at-half-maximum over energy ($\Delta E/E$) at some energy E (mostly at 662keV, the ^{137}Cs line) determines to a large extend whether or not a sensor is capable of resolving certain nuclides in the radiation spectrum. Bad resolution gives unusable data. Excellent resolution allows to identify sources of man-made radiation, or to separate radon from ^{238}U radiation. Spectral resolution is governed by the crystal type, the phototube and the multichannel electronics.

Linearity of a tool is another important factor. A tool must be “linear” against gamma energy, resolution and against temperature changes. In a calibration at Medusa, all three of these are checked and reported.

The perfect tool has:

- A fixed 1:1 linear relation between peak position (channel number) and peak energy;
- Zero offset and zero alinearity;
- Peak width scaling with $1/E^{1/2}$. In other words, a peak at 2000 keV has $1/\sqrt{2}$ times the resolution of a peak at 1000 keV.

However, in real life, of course no tool is perfect.

Industry standards

The table below shows a summary of the typical peak resolutions we have obtained over the years, for different tool types. We have ordered the tools into 3 groups: “Big crystals (airborne and oil&gas tools); “Slimline borehole” (the small-diameter tools used in mining) and “Optimum” (resolution reported by the crystal manufacturers). We show results for different crystal materials.

Table 1. Peak resolution summarized per crystal type and application. Resolution given at 662 keV as fraction $\Delta E/E$. Resolution given as averages found for the tool type.

App/Crystal	Typical size	NaI	CsI	BGO	CeBr
Big crystals	2-4 inch diameter / 4-16 inch length	8.5%	9.5%	11%	X
Slim line borehole tools	1-2inch diameter / 2-4 inch length	11%	12.5%	15%	X
Optimum		6%	7.5%	9.5%	4%

The numbers listed are used by us as reference, and could be considered the “industry standard”. However, it should be noted that – especially for the small-diameter tools we find a large spread in resolution (for NaI, the resolution we recorded for about 30 tools varies between 8.5% and 15%!).

We think that by careful choice of crystal type, photomultiplier tube and multichannel analyzer electronics, one should be able to “move” the quality of the tools used in mining, at least towards the oil&gas standards.

To see whether such is achievable, Medusa Sensing have, in collaboration with Scionix (Netherlands), started the development of a generic radiometric sensor that can be used in (slimline) borehole tools. Scionix have provided a high-resolution CeBr crystal (see image below) for testing and R&D.

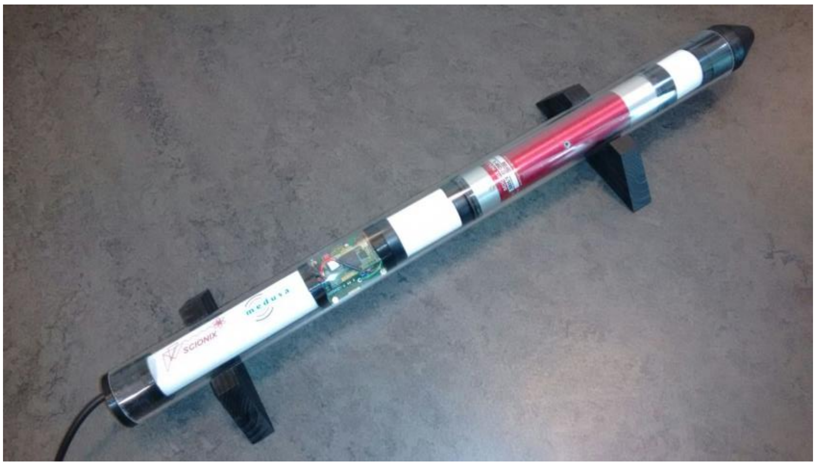

Figure 1. Test setup of a 1x1 inch CeBr tool coupled to the 1024 channel readout system. The diameter of the system shown is around 30mm.

We have done initial tests with this system in our Stonehenge calibration set-up [1] and with a ^{22}Na source, and the results are very promising.

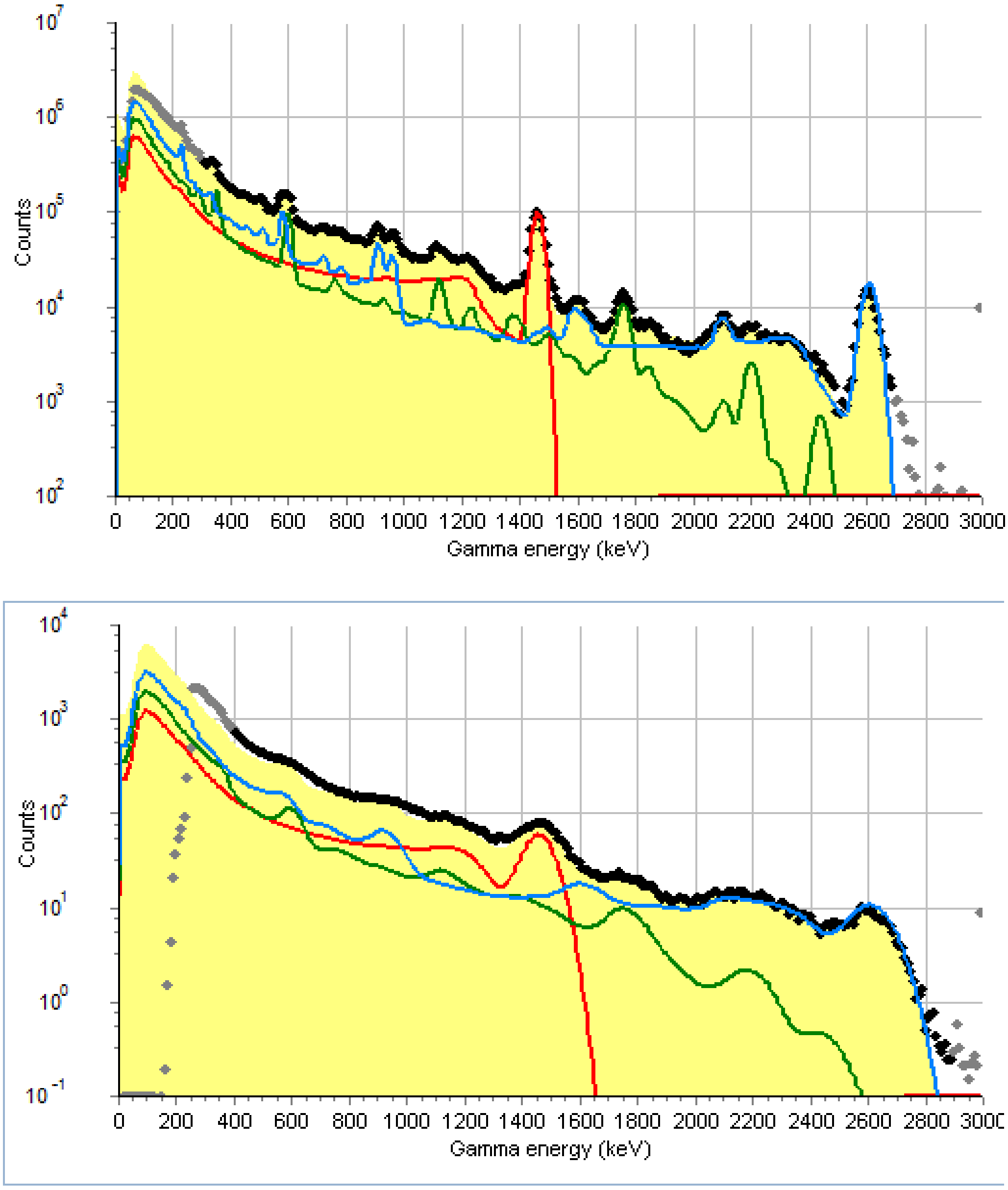

Figure 2. Spectra taken in the Medusa calibration setup. Top figure: our CeBr system. Bottom figure, same but for a commercial NaI system.

Figure 2 shows first results from a calibration measurement with the CeBr system (top) and a reference system mounted inside the Medusa Stonehenge setup. The black dots denote the measured spectrum. The yellow surface is the result of the fitting procedure (the “fitted” spectrum). The red, blue and green curves are the responses for K, Th and U radiation respectively.

The resolution we find for the CeBr system is about 3.9% at 662 keV. This is very close, if not right on top of the best resolution reported by the manufacturer (Scionix). The resolution of the reference system (a commercial NaI-based borehole logging system) shown, was 12.5%.

As one can see in figure 2, the improved peak resolution in our tool reveals a tremendous amount of spectral structure in the data!

To exclude the effect of the high-resolution CeBr, we did another test in our calibration set-up. Now the test (shown below in figure 3) was done with a NaI crystal, coupled to the mini-MCA shown in figure 1. The resolution we find for the NaI–based version of our new tool is 6.0%!

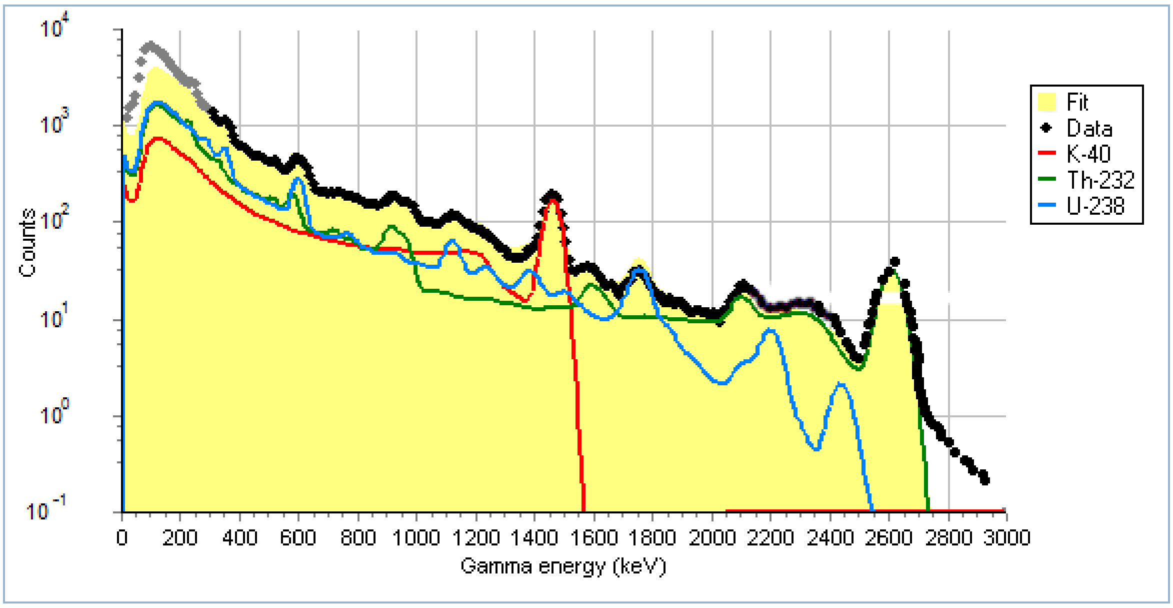

Figure 3. Same as figure 2, now using a NaI crystal mounted on the micro-MCA.

A Better resolution – so what?

In a (relatively) recent work, Keyser and Twomey[2] have discussed the relation between gamma-ray peak resolution and usability of detector systems for isotope identification. For a certain class containing (135 man-made) radionuclides, they show that improvement of the resolution of a gamma-ray detector by a factor of 5 increases the identification rate by 90%! Resolution is therefore key in reduction of false-positive identification of radionuclides.

We have found a similar effect of improvement of resolution on the quality of the spectral fit. In the figure below, we plot the uncertainty in ^{238}U versus the resolution of a gamma-ray spectrum. The figure is created using artificially created spectra, assuming a borehole-type source containing about 2% ^{40}K, 4 ppm ^{238}U and 10 ppm ^{232}Th, based on a 2x2 inch NaI detector. As can be seen in the figure, the uncertainty goes up from about 50% for the highest resolution to about 100% for low resolution crystals – a quite drastic effect especially if one considers that the uncertainties scale with the square of the count rates!

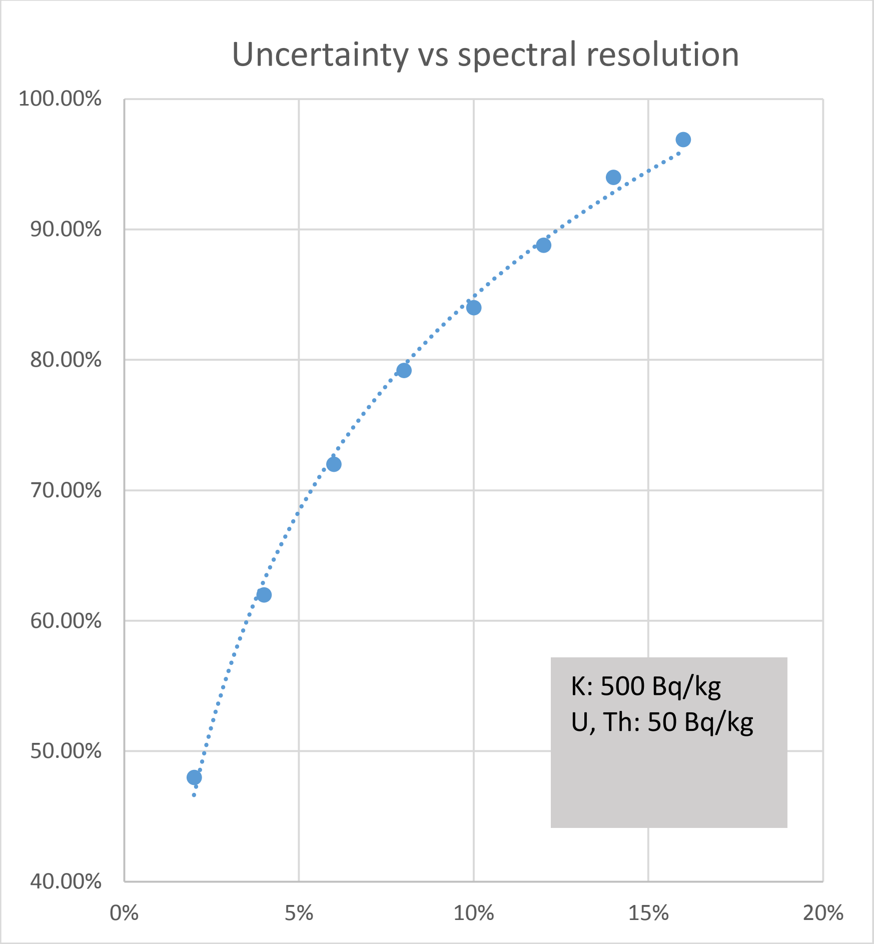

Figure 4. Uncertainty in ^{238}U determination versus resolution of the gamma spectrum.

Conclusion and outlook

The data taken with the new Medusa sensor show a significant improvement in resolution as compared to the “industry standard” systems. One could expect such an improvement when using CeBr as crystal material. But the results show that the improvement is not (only) due to the novel crystal material. Even with standard “NaI” as scintillator we get down to 6% resolution, which is similar to the optimum resolution!

App/Crystal	Typical size	NaI	CeBr
Medusa slim line tool	1-2inch diameter / 2- 4 inch length	6%	3.9%
Oil & Gas	2-4 inch diameter / 4-16 inch length	8.5%	X
Mining	1-2inch diameter / 2-4 inch length	11%	X
Optimum		6%	4%

We have also tested the linearity of the tool (data not shown here), to find that the tool acts perfectly linear against temperature and peak energy.

Our new tool allows for a significant step forward in improving gamma-ray (borehole) measurements in mining. Resolution is key to spectral analysis – at the end high-resolution spectra give much cleaner data and thereby much less noise in the nuclide concentrations.

The next step will be to “sensorize” the tool. That is, to integrate crystal, PMT and electronics all in just one robust package. The tool will be offered as a fully calibrated, turnkey solution with complete customization, logistic, and branding options to OEM’s.

References

[1] E. R. van der Graaf, J. Limburg, R. L. Koomans, and M. Tijs, “Monte Carlo based calibration of scintillation detectors for laboratory and in situ gamma ray measurements.,” *J. Environ. Radioact.*, vol. 102, no. 3, pp. 270–82, Mar. 2011.

[2] R. M. Keyser and T. R. Twomey, “Detector resolution required for accurate identification in common gamma-ray masking situations,” *J. Radioanal. Nucl. Chem.*, vol. 282, no. 3, pp. 841–847, 2009.