Stonehenge
Calibration report

Tool ID	MS-1000.9999
Calibration setup	Stonehenge (4π semi-infinite homogeneous source of known activity and density)
Date of calibration	February 30th, 2026
Version of report	1.0
Commissioned by	Client

Calibration by

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Contents

Fact sheet

General information	
Tool ID	MS-1000.9999
Model	MS-1000
Crystal type	CsI
Crystal dimensions	3x9” CsI
Crystal s/n	S1AB1234
MCA s/n	1234
Application	Droneborne/Walking
Calibration setup	Stonehenge (4π semi-infinite homogeneous source of known activity and density)
Read-out	mDOS
Calibration duration	Approximately 30 minutes
Date of calibration	February 30th, 2026
Commissioned by	Client

Calibration results	
Energy resolution @662 keV	8.1%
Overall scaling factor	97.3%
Energy scaling factors	
	a_0: -1.10
	a_1: 0.671
	a_2: 0.000004
Analysis interval	LLD: 370 keV
	ULD: 2770 keV
HV setting	0 V
Gain	21.0
Polarity	Negative
Standard spectra created	^{40}K, ^{137}Cs, ^{232}Th and ^{238}U
Calibration file(s)	1) MS-1000.9999_3x9CsI_30-02-26_KUTh.a2320.mcf
	2) MS-1000.9999_3x9CsI_23002-26_KUThCs.a2320.mcf

1 Summary

This report describes the calibration of a tool for the measurement of natural gamma radiation from soils and rock formations. The tool under consideration is a CsI "spectra gamma tool", and does support energy-resolved measurement of radiation. The tool was calibrated against the Stonehenge setup, a semi-infinite cube of brick of density 2.32 kg/l.

The measurements were carried out on March 25th, 2026, using the Stonehenge setup at the Medusa facility in Groningen, The Netherlands.

The results of the calibration are:

- The energy resolution of the system is 8.1% @ 662 keV (^{137}Cs);
- The overall scaling factor for the system is 97.3%. This implies that the system provides 97.3% of the theoretical maximum efficiency;
- The energy scaling factors of the system are (a_0=-1.10, a_1=0.671; a_2=0.000004).

2 Assignment

The goal of the calibration is to retrieve a set of *standard spectra*; response curves of the tool against a source of unity activity and given geometry. In this case, the tool is calibrated against the Medusa Stonehenge facility.

2.1 Tool description

The tool is a 3x9” CsI detector and is intended for Droneborne/Walking. The device was readout using mDOS.

2.2 Measurement setup

The tool was inserted into the Stonehenge setup at the Medusa facility in Groningen, The Netherlands. Inside the setup, the tool was set to record gamma spectra during a period of Approximately 30 minutes.

3 Calibration

3.1 Stonehenge calibration setup

Figure 1. The Stonehenge calibration setup

The tool was calibrated using the Stonehenge calibration setup. Stonehenge is a brick castle (outer dimensions: 120x120x120 cm^3) with a horizontal square (20x20 cm^2) opening at the front in which a detector under test may be entered. The opening was closed on the front and the end by 15 cm thick blocks leaving only a 6x6 cm^2 square opening. The radionuclide concentrations of the bricks were measured using gamma ray spectrometry and are presented in Table 1.

Table 1. Radionuclide concentrations in Stonehenge bricks.

Radionuclide	Concentration (Bq/kg)	Concentration (ppm or %)	Concentration as oxides (ppm or %)
^{232}Th	52	13 ppm Th	14.64 ppm ThO_2
^{238}U	41	3.33 ppm U	3.94 ppm U_3O_8
^{40}K	535	1.69% K	2.08% K_2O

The Stonehenge calibration facility has been modeled using a Monte Carlo Simulation code (MCNPX). In the simulations, the bricks were assumed to be pure SiO_2 with a density of 2.32 kg dm^{-3}. Air was taken as a mixture of N_2 (79 % mass) and O_2 (21% mass) with a density of 1.293 kg m^{-3}.

3.2 Monte Carlo Models

Using the Monte Carlo code, a model was created for 3x9" CsI crystal present in the tool. The model also includes most other components of the tool which may have an influence on the spectrum being collected.

For the model, response curves were simulated assuming 1 Bq/kg sources of ^{40}K, ^{137}Cs, ^{238}U and ^{232}Th in the Stonehenge geometry. Such a response curve is called a pure spectrum or *standard spectrum* and represents the spectrum one would measure in the hypothetical situation of a tool inside a Stonehenge-type geometry having an activity of 1 Bq/kg.

3.3 Calibration procedure

The next step in the calibration of a tool is to measure a gamma spectrum inside the Stonehenge setup. The spectrum measured is subsequently energy stabilized, normalized and approximated by the Monte Carlo calculated unbroadened histograms. In this approximation procedure, the following steps are applied:

1. Determination of the spectral resolution of the tool; the unbroadened response histograms are energy-broadened to fit the spectral resolution of the detector;

2. Determination of a general scaling factor describing the difference between a theoretical tool response (response without losses) and the actual response;

3. Determination of a function mapping the “raw” multichannel spectral data to an energy-calibrated spectrum. This procedure basically determines the function needed to map a channel in the MCA spectrum to energy in the energy spectrum. In most cases a quadratic mapping function is used, described by three parameters a_0, a_1 and a_2. These a-factors are the coefficients of the 2^{nd} order function translating the channel numbers into energy.

    - a_0 represents the channel offset present in the multichannel system

    - a_1 represents the (temperature dependent) linear scaling factor;

    - a_2 represents an alinear correction to the channel-energy scaling

    In an ideal multi-channel system, the factors a_0 and a_2 would be zero and a_1 varies solely with the temperature of the system (c.f. Hendriks *et al*, 2001);

4. Converting the calibration geometry into the geometry for the application in which the tool is going to be used. In this case, the tool will be used in a Droneborne/Walking application which implies a “semi 2-pi” geometry.

These steps are described in detail in Van der Graaf *et al*, 2008. The result of the calibration procedure is a set of standard spectra that can be used in Full Spectrum Analysis to analyze gamma-ray data measured in the field.

The output of the calibration procedure is a Medusa Calibration File (MCF) that can be used in the Medusa spectral analysis software.

3.4 Calibration results

The spectra recorded were summed and analyzed according to the procedure listed above.

The results of the calibration are the following;

- The energy resolution of the system is 8.1% @ 662 keV (^{137}Cs);
- The overall scaling factor for the system is 97.3%. This implies that the system provides 97.3% of the theoretical maximum efficiency;
- The energy scaling factors of the system are (a_0=-1.10, a_1=0.671; a_2=0.000004).

The figures below show the measured spectrum along with the unbroadened response histograms and the standard spectra.

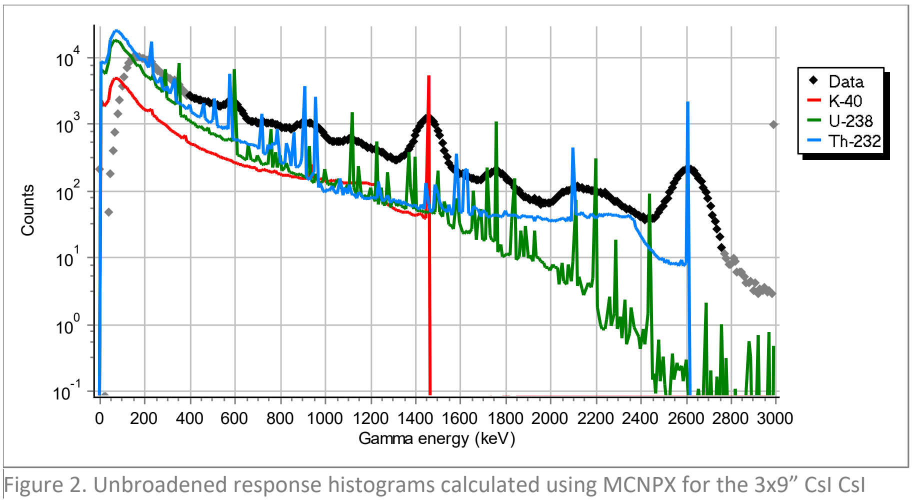

Figure 2. Unbroadened response histograms calculated using MCNPX for the 3x9" CsI CsI System. The curves represent the response to a ^{40}K source (red curve), a ^{238}U source (green curve) and a ^{232}Th source (blue curve) respectively. Note the large numbers of decay lines for the U and Th series. ^{40}K has a single decay line at E=1460 keV.

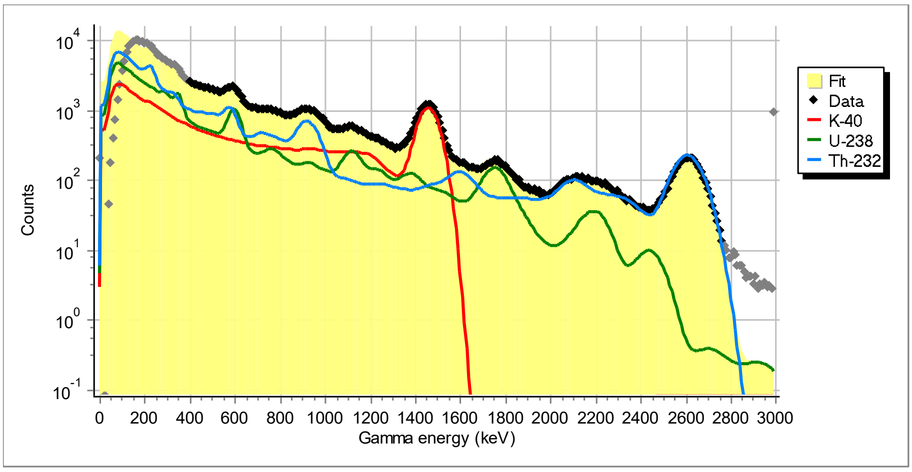

Figure 3. Spectrum measured inside Stonehenge (black dots), standard spectra (red, green and blue for ^{40}K, ^{238}U and ^{232}Th respectively) and resulting fit (yellow surface). The standard spectra are the broadened versions of the lines in the figure above.

3.5 Remarks

1. The overall scaling factor of 97.3% is excellent;
2. The offset and alinearity of the tool (factors a_0 and a_2) are well within the quality limits for a spectral gamma tool;
3. This calibration is valid for a (center) height of 80 cm above the surface. Other heights may result in slightly different values.

4 Definition of calibration parameters

Energy resolution

The resolution of the spectrum describes the width of the photo peaks. The resolution is calculated as the full width at half maximum (FWHM) for a ^{137}Cs photo peak at 662 keV. The resolution depends on the configuration and electronics, but it is largely determined by the intrinsic properties of the scintillation crystal.

During the calibration, the resolution has been determined over the complete spectrum. The FWHM depends on the energy of the photo peak, and is presented in this report for 662 keV.

Overall scaling factor

A Monte Carlo model has been created to describe the spectrometer to be calibrated. The Monte Carlo model is used to generate the histograms which describe the response of the system to the calibration set-up. Aside from the crystal itself, materials and dimensions of all other system parts may have an effect on the response of the system and need to be included into the model as well. The Monte Carlo model never perfectly describes the system and even systems from the same series may differ slightly. As a result, there is often a slight difference between the measured spectrum and the generated spectrum, which can be corrected for by applying a scaling factor. The scaling factor is typically close to 100%.

Energy spectrum

An energy spectrum consists of 300 channels with 10 keV per channel. An energy spectrum describes a range from 0 to 3000 keV.

Standard spectrum

The standard spectrum describes the response of the calibrated system for 1 unit of activity. Normally, the unit is provided in Bq/kg of a radionuclide in the geometry for which the system has been calibrated. A standard spectrum is also an energy spectrum.

A calibration file (MCF file) contains a set of standard spectra, one for each radio nuclide in the file.

Analysis interval

The analysis interval is the range where the measured spectrum matches the standard spectra based on the Monte Carlo simulations. This range is defined by a lower level discriminator (LLD) and an upper level discriminator (ULD). During the calibration process, the LLD and ULD are determined by searching for the points where the measured spectrum starts to differ from the combined standard spectra.

a_0, a_1 and a_2 parameters

The a_0, a_1 and a_2 parameters are the coefficients of a 2nd order function translating the channel numbers of a measured spectrum into energy.

- a_0 represents the channel offset present in the multichannel system;
- a_1 represents the (temperature dependent) linear scaling factor;
- a_2 represents an alinear correction to the channel-energy scaling.

In an ideal system, the factors a_0 and a_2 would be zero and a_1 varies solely with the temperature of the system (c.f. Hendriks et al, 2001). In practice, most systems show some offset ($a_0 <> 0$) and/or some alinearity ($a_2 <> 0$).

The a_0, a_1 and a_2 parameters are independent of the length of the measured spectrum and always transfer a 512 channel measured spectrum into a 300 channel energy spectrum.

Each channel in the measured spectrum describes an energy range in the energy spectrum, the lower bound of which can be calculated using:

$$S_{lower}(i) = a_0 + f a_1 i + f^2 a_2 i^2$$

Here S_{lower} is the lower bound in the energy spectrum for channel i in the measured spectrum. f is a scaling parameter defined as 512 divided by the number of channels in the measured spectrum (for a measured spectrum with 256 channels, f would be 2). Note that the upper boundary of the energy range for channel i is equal to the lower boundary of the next channel:

$$S_{upper}(i) = S_{lower}(i + 1)$$

Gamman and the GammaBase DLL use a highly optimized version of the equations above to convert the measured spectrum to an energy spectrum.

5 References

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Hendriks, P.H.G.M., Limburg, J. and de Meijer, R.J. 2001. Full-spectrum analysis of natural [gamma]-ray spectra. *Journal of Environmental Radioactivity*, **53**: 365-380.

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Pelowitz, D. B., ed., 2005. MCNPX User's Manual, Version 2.5.0, Los Alamos National Laboratory report LA-CP-05-0369.

Van der Graaf, E., J. Limburg, R.L. Koomans and M. Tijs. 2011.Monte Carlo based calibration of scintillation detectors for laboratory and in situ gamma ray measurements. Journal of Environmental Radioactivity, **102**: 270-282.