NGU REPORT
2024.016

A comparison of transportable and fixed calibration pads for airborne gamma-ray spectrometers

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Geology for society

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Report no.: 2024.016
ISSN: 0800-3416 (print)
ISSN:2387-35150 (digital)
Grading: Open

Title: A comparison of transportable and fixed calibration pads for airborne gamma-ray spectrometers

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Client: NGU
County:
Municipality:

Map-sheet name (M=1:250.000):
Map-sheet name (M=1:50.000):
Deposit name and grid-reference:
Numbers of pages: 17
Price (NOK): 40

Map enclosures:
Fieldwork carried out:
Date of report: May 2024
Project no.: 335900
Person responsible: Marco Brönner
Keywords: spectrometer, calibration, mobile pad, Borlänge, radiation, helicopter

Summary:

NGU owns and uses a set of transportable concrete calibration pads for calibration of its airborne gamma-ray spectrometers. The pads are principally designed for hand-held instruments, in contrast with larger fixed pads which are specially designed for airborne systems. Such a set of fixed pads are maintained by the Swedish Geological Survey (SGU) at Dala airport, Borlänge. In August 2012 NGU's airborne system was calibrated using the Borlänge pads, allowing a comparison between transportable and fixed calibration pads. A comparison of the two calibration methods shows little significant differences. As such NGU's calibration pads are a suitable and convenient substitute for dedicated fixed calibration pads. Calibration parameters obtained in recent years from the NGU pads are also provided as a monitor of long-term instrument stability.

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1. INTRODUCTION

NGU operates helicopter-borne gamma-ray spectrometers for use in airborne geological surveying. The instruments record radiation from naturally occurring radioisotopes and require calibration for stripping and sensitivities to potassium-40, uranium-238 and thorium-232.

NGU maintains a set of portable concrete calibration pads for calibration of its airborne gamma-ray spectrometers. The pads are primarily designed for small hand-held instruments, in contrast with larger fixed pads which are designed for airborne systems. Such a set of fixed pads are maintained by the Swedish Geological Survey (SGU) at Borlänge airport and are used to calibrate their fixed-wing airborne systems. In August 2012 NGU's helicopter-mounted airborne system was calibrated using the Borlänge pads, enabling a comparison of the portable-pad and fixed-pad calibration methods. This report compares the calibration factors (stripping ratios and sensitivities) obtained on small portable pads with those obtained on large, fixed pads. Calibration parameters obtained in recent years from NGU's portable pads are also provided as a monitor of instrument stability.

2. SPECTROMETERS

NGU operates an RSX-5 (Radiation Solutions Inc, Ontario, Canada) airborne gamma-ray spectrometer which consists of 5 x 4-litre NaI crystals. Four of the crystals are mounted in the lower part of the instrument housing and are commonly referred to as "downward looking"; a fifth crystal ("upward looking") is mounted on top of the lower crystals and is used to assist in separating the signals from airborne radon and ground uranium. Data are processed in an onboard 1024-channel spectrometer and can be stored on the device or transferred to a PC/laptop for real-time monitoring and post-flight analysis.

During geological surveys the spectrometer is typically mounted on the underside of a helicopter with around 25 cm clearance between the ground and the underside of the detector housing. The detector can also be mounted in fixed-wing aircraft or cars/vans, as appropriate to the survey requirements.

From 2013-2016 NGU have operated and maintained a second RSX-5 system (SN5645) on behalf of DSA (Norwegian Radiation Protection Authority). At the time of Borlänge calibration study, only one RSX-5 system was available. All measurements reported here were carried out with the NGU (SN5574) system.

As part of the Norwegian Atomberedskap NGU and DSA bought another RSX-5 spectrometer (SN6039) in 2021, which is stored and maintained by NGU. While this instrument is primarily meant to enforce the national Atomberedskap, it is also used for surveying when NGU needs it.

3. CALIBRATION PADS

Gamma spectrometer calibration pads typically consist of four pads, one each containing elevated concentrations of potassium-40, uranium-238 and thorium-232, and a fourth pad containing background concentrations of the same isotopes. They enable the calculation of stripping coefficients (which describe the contribution of isotopes to the energy-windows of other isotopes) and sensitivities (which describe the relationship between count rates in the detector and isotope concentrations in the ground).

Airborne gamma-ray spectrometry systems are typically calibrated on large (around 10 m) diameter calibration pads. Such pads are regarded as being sufficiently large, relative to the detector size, to approximate an infinite plane source, and can be used to determine stripping coefficients for the detector system. Calibration pads can also be used to determine sensitivities at zero altitude, although other methods based on calibration lines are recommended (IAEA 2003). Pad-derived zero-altitude sensitivities can be used together with height-dependent attenuation coefficients (determined during surveys) to obtain survey-altitude sensitivities.

Transportable (ca 1m x 1m x 0.3m) calibration pads are designed principally for hand-held portable spectrometers, where detector crystal volumes may be of the order of 0.1- 0.2 litres. Grasty et. al. (1991) demonstrated that such transportable pads could also be used to determine stripping coefficients for larger volume (typically ca. 16 litres) airborne systems. The authors compared the stripping coefficients obtained on large (8 m x 8 m) aircraft calibration pads with those obtained from portable calibration pads and found them to be in good agreement. No such comparison of zero-altitude sensitivities was reported.

Because transportable pads have a relatively small surface area, a geometrical correction factor is required to account for the non-infinite pad size. These geometrical factors (typically 10-20%) are determined by Monte Carlo modelling and are applied to hand-held detector calibrations to obtain sensitivities to infinite planes. The correction factors are determined for small (< 0.2 litre) detector systems placed centrally on the calibration pads but have also been used by NGU in determining the sensitivity of their airborne systems. It might be anticipated, however, that a larger volume system, covering around 40% of the pad surface area, would require larger geometrical correction factors. Sensitivity calibrations on large aircraft pads do not typically require the use of geometrical correction factors, and hence a comparison of NGU pads with the Borlänge pads will allow to estimate the suitability of NGU's current geometrical correction factors.

3.1 NGU calibration pads

NGU maintains a set of concrete calibration pads (Grasty et al.1991) which are regularly used to calibrate both hand-held and airborne systems. Each of the four pads measures 1m x 1m x 0.3 m. Three of the pads contain enhanced concentrations of potassium-40, uranium-238 and thorium-232 respectively; the fourth pad contains background concentrations of potassium, uranium, and thorium. Pad properties are given in Table 1.

Table 1: Properties of NGU's calibration pads. From Grasty 1990.

Pad	K (%)	eU (ppm)	eTh (ppm)	Density (g/cm^3)	Geometrical factor
Background	1.34 ± 0.01	0.98 ± 0.02	2.28 ± 0.07	2.18	-
Potassium	7.98 ± 0.18	0.46 ± 0.03	1.82 ± 0.06	2.13	1.16
Uranium	1.25 ± 0.01	53.33 ± 1.0	3.2 ± 0.09	2.2	1.17
Thorium	1.34 ± 0.01	2.31 ± 0.04	110.0 ± 1.42	2.3	1.19

3.2 SGU calibration pads

SGU maintains a set of 4 calibration pads at Dala airport, Borlänge, Sweden (Jelinek at al., 2005). The circular pads are 10 m in diameter and are linearly aligned with approximately 30 m separation between pad centres (Figure 1, Figure 2). The pads are 0.5 m thick with their upper surfaces at ground level. They are constructed of 22,000 concrete bricks doped with various concentrations of potassium-40, uranium-238 and thorium-232. Pad properties are given in Table 2.

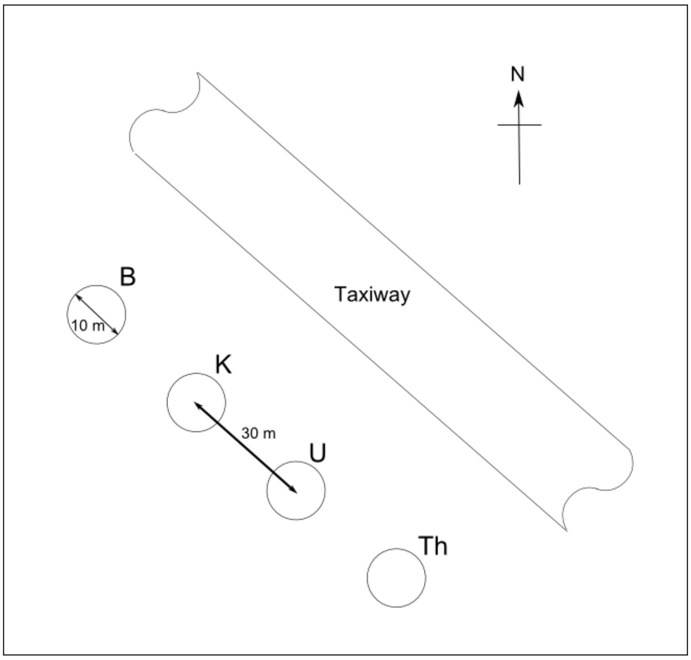

Figure 1: Schematic of SGU calibration pads at Dala airport. B, K, U and Th denote the background, potassium-40, uranium-238 and thorium-232 pads respectively.

Table 2: Properties of the SGU calibration pads. From Jelinek et al., 2005.

Pad	K (%)	eU (ppm)	eTh (ppm)
Background	0.4 ± 0.1	1.5 ± 0.1	2.4 ± 0.7
Potassium	7.5 ± 0.1	1.0 ± 0.2	1.3 ± 0.7
Uranium	0.7 ± 0.0	24.8 ± 2.7	2.6 ± 0.7
Thorium	0.6 ± 0.0	3.6 ± 0.2	49.1 ± 2.9

Figure 2. Calibration pads at Borlänge, Sweden.

4. CALIBRATION METHOD

The detector to be calibrated is placed by landing the helicopter on each of the calibration pads in turn, and count rates are recorded in each of three energy windows corresponding to the photopeaks of potassium-40, bismuth-214 and thalium-208 respectively, and where the bismuth and thallium signals are assumed to be representative of the activities of the uranium-238 and thorium-232 series. Data are collected using RadAssist (RSI) software provided by the detector manufacturer.

The signal from the background pad is subtracted from each of the other three pads. Subtracting the background pad signal has the effect of a) removing environmental background, which is assumed to be the same around each calibration pad, and b) removing the contributions from background elements in each pad. The Th pad, for example, in addition to containing relatively high concentrations of thorium, contains small amounts of uranium and potassium. Similar concentrations of uranium and potassium are present in the background pad, and so after background subtraction we are left with a signal approximating that from a pure thorium source, allowing the determination of the contribution of thorium to the uranium and potassium windows. In practice, however the background levels in the pads are not identical, and there are small residual contributions of background elements in each pad even after background subtraction. These residual contributions are taken account of by using a matrix analysis procedure. This approach, including the determination of the sensitivity matrix, stripping coefficients, and sensitivities are outlined in Appendix A.

4.1 Calibration at NGU

Measurements were made in March 2012 in the NGU car park on each of the NGU calibration pads B, K, U and Th. During measurements each pad was positioned at the same marked location on the ground, while pads not in use were positioned around 20 m away from the measurement location. The detector was placed such that the detector crystals were approximately centrally located, and directly on the surface of each pad though it is not ideal for measurement as per IAEA recommendations that recommends keeping detector ca. half meter above the pads instead of directly placing over it. Data were collected for a period of at least 10 minutes on each pad. A background pad measurement was performed first, and a second background measurement was performed after the K, U and Th pad measurements. The average of the two background measurements was used in the subsequent analysis. All measurements were performed on the same day within a time-window of around 2 hours. Weather conditions on the day were dry.

4.2 Calibration at Borlänge

NGU visited Dala airport, Borlänge in June 2012 with their helicopter-mounted RSX-5 system. Measurements were made on each of the B, K, U and Th pads, with the detector mounted on the underside of the helicopter such that ground-to-detector clearance was around 25 cm. The helicopter was positioned such that the centre of the detector crystals was approximately central on each pad. Data were collected for around 10 minutes on each pad. A background pad measurement was performed first, and a second background measurement was performed after the K, U and Th pad measurements. The average of the two background measurements was used in the subsequent analysis. All measurements were performed on the same day within a time-window of around 2 hours. Weather conditions on the day were dry; there had been some light rain in the area on the previous day up until around 1pm.

5. CALIBRATION RESULTS

Energy windows were determined based on the NGU pad calibrations; the same energy windows are used in both calibration methods. The energy windows are indicated in Table 3. The lower and upper channel limits are inclusive - the K window for example includes the channels 455 to 522. One channel corresponds to 3 keV gamma energy. However, RadAssist recommended energy windows are used from 2016 onwards because RSX-5 stabilises on natural radioelements and there is no need of energy calibration.

Table 3: Energy windows for K, U and Th.

Element	Window channels (before 2016)		Window channels (after 2016)	
	Lower	Upper	Lower	Upper
K	455	522	457	523
U	552	618	553	620
Th	802	935	803	937

5.1 NGU pad calibrations

Table 4 shows the background-corrected average counts-per-second on each pad in each of the K, U and Th energy windows for the 10 minutes recording. The table values include a small correction to the thorium pad as outlined in IAEA (2003, p.54.) The cell values in Table 4 can be interpreted as the elements of the matrix *N* in Appendix A.

Table 5 shows the pad concentrations after subtraction of the background pad concentrations. The cell values can be interpreted as the elements of matrix *C* in Appendix A. Note that because the background concentrations in each pad vary slightly, and are not identical to the element concentrations in the background pad, negative concentrations are possible in the matrix *C*. This is consistent with the negative counts-per-second obtained in some cells after background subtraction in Table 4.

The cells in Table 6 correspond to the elements of the sensitivity matrix *S* obtained from the procedure described in Appendix A.

Table 4: Background-corrected counts per second in the element windows on each pad, NGU

		Pad		
		K	U	Th
Window	K	750.28	415.6	290.1
	U	-6.4	510.9	189.1
	Th	-3.7	29.7	572.1

Table 5: NGU pad concentrations after subtracting background-pad concentrations

		Pad		
		K	U	Th
Concentration	K (%)	6.64	-0.09	0
	U (ppm)	-0.52	52.35	1.33
	Th (ppm)	-0.46	0.92	107.72

Table 6: Sensitivity matrix values, NGU

Sensitivity matrix		
113.88	8.089	2.593
-0.08461	9.731	1.636
-0.1377	0.4710	5.453

5.2 Borlänge pad calibrations

Tables 7, 8 and 9 show results from the Borlänge pads, and are the equivalent of Tables 4, 5 and 6 for the NGU pads.

Table 7: Background-corrected counts per second in the element windows on each pad, Borlänge

		Pad		
		K	U	Th
Window	K	874.6	270.6	174.7
	U	-4.099	267.5	111.0
	Th	-5.146	19.35	268.8

Table 8: Borlänge pad concentrations after subtracting background-pad concentrations

		Pad		
		K	U	Th
Concentration	K (%)	7.1	0.3	0.2
	U (ppm)	-0.5	23.3	2.1
	Th (ppm)	-1.1	0.2	46.7

Table 9: Sensitivity matrix values, Borlänge

Sensitivity matrix		
124.3	9.990	2.758
0.5175	11.46	1.859
0.2164	0.7786	5.721

5.3 Comparison of stripping coefficients and sensitivities

Tables 10 and 11 show a comparison of stripping coefficients and sensitivity between NGU mobile pads and Borlänge fixed pads. They are in good agreement.

Table 10: Comparison of stripping coefficients from NGU and Borlänge. Values in brackets are estimated standard deviations using PADWIN.

Stripping coefficients			
	NGU	Borlänge	Ratio (NGU/Borlänge)
α	0.300 (0.0015)	0.325 (0.0139)	0.92 (0.04)
β	0.476 (0.0034)	0.482 (0.0430)	0.99 (0.09)
γ	0.831 (0.0042)	0.872 (0.0447)	0.95 (0.05)
a	0.048 (0.0014)	0.068 (0.0205)	0.71 (0.22)
b	-0.0012 (0.0007)	0.0017 (0.0077)	-0.67 (2.98)
g	-0.0007 (0.0006)	0.0042 (0.0039)	-0.17 (0.21)

Table 11: Comparison of sensitivities from NGU and Borlänge. The columns NGU* and Ratio* are those obtained after applying the geometrical correction factors provided by the pad manufacturers. Values in brackets are estimated standard deviations using PADWIN.

	NGU	Borlänge	Ratio (NGU/Borlänge)	Geom. factor	NGU*	Ratio*
K (%K/cps)	0.00878 (0.00024)	0.00804 (0.00017)	1.09 (0.04)	1.16	0.0076	0.94 (0.03)
U (ppm eU/cps)	0.103 (0.002)	0.0873 (0.0101)	1.18 (0.14)	1.17	0.0878	1.00 (0.12)
Th (ppm eTh/cps)	0.183 (0.002)	0.175 (0.011)	1.05 (0.07)	1.19	0.1541 (0.002)	0.88 (0.06)

5.4 Uncertainties

Uncertainties in radioactive count rates are generally treated by assuming that counts follow a Poisson distribution such that the uncertainty in a number of counts N is given by $\sigma = \sqrt{N}$. The measurement periods used here have been sufficiently long that statistical errors, even after propagation of errors have been determined, are small - statistical errors on α, β, γ stripping coefficients are of the order half of one percent or less, and statistical errors on sensitivities are of the order 0.1-0.2 percent. Overall uncertainties on these quantities will be dominated by uncertainties in the pad concentrations. For the NGU pads, uncertainties are the order 1-2% for the diagonal elements of the matrix C, and up to a few percent for off-diagonals; the Borlänge pads have considerably higher (up to 11%) uncertainties.

(The stripping coefficients a,b and g have larger statistical errors due to the lower resultant background-subtracted counts involved, however, these stripping coefficients, being small, are relatively unimportant when processing survey data).

The uncertainties reported in Tables 10 and 11 were determined using the program PADWIN (Løvborg 1981) which uses regression techniques to arrive at a solution. The program gives stripping and sensitivity results consistent with the matrix methods used above, but additionally calculates uncertainties taking both counting statistics and pad uncertainties into account.

6. CALIBRATION MONITORING

Stripping coefficients and sensitivity measured on the NGU pads for both the NGU and DSA spectrometers are provided in Appendix B till date. Changes to calibration parameters for the NGU system have been (relative to 2010) within 5% of the 2010 values, and those of the DSA system have been within 2% of the 2013 values. Year-on-year changes are generally smaller than this. The calibration parameters do not exhibit any obvious trend with time which might indicate a degradation in the instrument performance. Calibration parameters for the two systems are similar.

NGU and DSA bought another RSX-5 spectrometer in 2021. The calibration factors for newer RSX-5 (SN6039) are also provided in Appendix B.

7. CONCLUSIONS

Stripping and sensitivities obtained from the two sets of pads are in good agreement. Stripping factor ratios (α, β and γ) and sensitivity ratios between the two methods are consistent with 1 at the one sigma level, with the exception of α and sensitivity for thorium which are consistent with 1 at the two-sigma level. The NGU portable calibration pads are therefore a suitable and convenient substitute for larger fixed calibration pads. Calibration parameters from year to year appear to be stable, with fluctuations within a few percent, and with no obvious degradation over time.

8. REFERENCES

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APPENDIX A

Deriving stripping coefficients and sensitivities from calibration pad count rates

The following is based on IAEA 2003, pp 35-38.

For each of the four pads, let n_i (i=1-3) represent the count rates in the K, U and Th windows respectively. The count rates in each window will be given by

$$n_i = s_{iK}c_K + s_{iU}c_U + s_{iTh}c_{Th} + n_{iBG}$$

Here s_{iK}, s_{iU} and s_{iTh} represent the sensitivities of the spectrometer's *i*-th energy window to K, U and Th respectively; c_K, c_U and c_{Th} represent the concentrations of K, U and Th in the pad, and n_{iBG} is the contribution of background (surrounding environment, cosmic rays, instrument background) to the energy window.

The background contribution can be removed by subtracting the count rates obtained on the background pad, and by assuming that environmental background conditions are identical for all pad measurements. If we subtract the count rate in the background pad from each of the K, U and Th pads, and subtract the background pad concentrations from each of the K, U and Th pad concentrations, we obtain:

$$n'_i = s_{iK}c'_K + s_{iU}c'_U + s_{iTh}c'_{Th}$$

Here n_i' represents the difference in count rates between each of the K, U and Th pads and the background pad; c_K', c_U' and c_{Th}' represent those differences in K, U and Th concentrations between each calibration pad and the background pad.

The above is true for each of the K, U, and Th pads; for each pad we have:

$$n'_{iK} = s_{iK}c'_{KK} + s_{iU}c'_{UK} + s_{iTh}c'_{ThK}$$

$$n'_{iU} = s_{iK}c'_{KU} + s_{iU}c'_{UU} + s_{iTh}c'_{ThU}$$

$$n'_{iTh} = s_{iK}c'_{KTh} + s_{iU}c'_{UTh} + s_{iTh}c'_{ThTh}$$

This can be represented in matrix form as

$$N = SC$$

where *N, S* and *C* are 3x3 matrices. Each element n_{ij} represents the background-corrected count rates in the *i*-th energy window on the *j*-th calibration pad; s_{ij} represents the sensitivities of the spectrometer in the *i*-th energy window to the *j*-th element, and c_{ij} represents the background-corrected pad concentrations of the *i*-th element on the *j*-th pad.

We can obtain the matrix *S* by inverting:

$$S = NC^{-1}$$

The elements of *S* can be denoted as follows:

$$S = \begin{bmatrix} S_{KK} & S_{KU} & S_{KTh} \\ S_{UK} & S_{UU} & S_{UTh} \\ S_{ThK} & S_{ThU} & S_{ThTh} \end{bmatrix}$$

and where S_{KU} for example represents the contribution of uranium to the potassium energy window.

The stripping constants α, β, γ, a, b and g can be obtained from the matrix *S* as follows:

$$\alpha = \frac{S_{UTh}}{S_{ThTh}}$$

$$\beta = \frac{S_{KTh}}{S_{ThTh}}$$

$$\gamma = \frac{S_{KU}}{S_{UU}}$$

$$a = \frac{S_{ThU}}{S_{UU}}$$

$$b = \frac{S_{ThK}}{S_{KK}}$$

$$g = \frac{S_{UK}}{S_{KK}}$$

The sensitivities to each of the element K, U and Th are obtained from the diagonal elements of *S*, with units of count-rate-per-unit-concentration. Inverting each of these terms gives us sensitivities in %K/cps, ppm eU/cps and ppm eTh/cps respectively.

APPENDIX B

Monitor of instrument stability.

Since 2002 NGU has performed routine checks of stripping coefficients and sensitivities on the NGU pads. Table B1 shows the calibration factors for the NGU (SN5574) system, Table B2 those for the DSA (SN5645) system (since 2013) and Table B3 for the Atomberedskap (SN6039) system acquired in 2021.

Note that around 2009-2010 a reconditioning of the NGU system was carried out by the manufacturers. This included adjustment of the spectrometer to record in 1024 channels. In addition, at the same time the calibration analysis procedure was adjusted to use a matrix method (Appendix A) which takes into account residual concentrations in the background-corrected pads, and an underestimate of counts in the thorium channel due to coincidence events appearing in the cosmic channel (IAEA, 2003 p.54). These make small but noticeable differences to the calibration results.

For this reason, changes in parameters are provided from, and relative to, 2010 calibrations (for the NGU system). Changes are provided relative to 2013 for the DSA system (the date of first use by NGU).

Since 2022, the channel windows have been adjusted to the recommendation from RSI. The calibration is also performed with the instrument elevated above the concrete calibration pads. Minor changes are seen between 2021 and 2022.

Table B1: Calibration parameters for NGU (SN5574) spectrometer

NGU system (SN5574)												
	Calibration year											
	2002	2005	2008	2010	2012	2013	2014	2015	2016	2017	2019	2020
$\boldsymbol{\alpha}$	**0.304**	**0.313**	**0.315**	**0.309**	**0.300**	**0.297**	**0.304**	**0.307**	**0.306**	**0.298**	**0.305**	**0.306**
% change in $\boldsymbol{\alpha}$ since 2010					-2.8	-3.8	-1.5	-0.7	-0.9	-3.5	-1.1	-0.7
$\boldsymbol{\beta}$	**0.514**	**0.512**	**0.513**	**0.481**	**0.475**	**0.471**	**0.467**	**0.480**	**0.476**	**0.463**	**0.472**	**0.471**
% change in $\boldsymbol{\beta}$ since 2010					-1.1	-1.9	-3.0	-0.2	-1.0	-3.6	-1.8	-2.0
$\boldsymbol{\gamma}$	**0.764**	**0.753**	**0.740**	**0.795**	**0.831**	**0.829**	**0.806**	**0.821**	**0.824**	**0.796**	**0.829**	**0.822**
% change in $\boldsymbol{\gamma}$ since 2010					4.5	4.2	1.3	3.2	3.7	0.0	4.2	3.4
S_K (% K-40/cps)	**0.00738**	**0.00618**	**0.00651**	**0.00762**	**0.00757**	**0.00754**	**0.00756**	**0.00750**	**0.00753**	**0.00760**	**0.00757**	**0.00757**
% change in S_K since 2010					-0.6	-0.9	-0.8	-1.5	-1.1	-0.2	-0.6	-0.5
S_U (ppm eU / cps)	**0.0868**	**0.0734**	**0.0736**	**0.0867**	**0.0878**	**0.0889**	**0.0877**	**0.0879**	**0.0882**	**0.0887**	**0.0887**	**0.0884**
% change in S_U since 2010					1.3	2.6	1.2	1.4	1.8	2.4	2.3	1.9
S_{Th} (ppm eTh / cps)	**0.176**	**0.154**	**0.155**	**0.157**	**0.154**	**0.151**	**0.153**	**0.153**	**0.152**	**0.150**	**0.152**	**0.153**
% change in S_{Th} since 2010					-2.0	-3.7	-2.9	-2.6	-3.1	-4.4	-3.5	-2.8

Table B2: Calibration parameters for DSA (SN5645) spectrometer

DSA system (SN5645)				
	Calibration year			
	2013	2014	2015	2016
$\boldsymbol{\alpha}$	**0.303**	**0.306**	**0.309**	**0.302**
% change in $\boldsymbol{\alpha}$ since 2013		0.7	1.8	-0.5
$\boldsymbol{\beta}$	**0.480**	**0.484**	**0.476**	**0.480**
% change in $\boldsymbol{\beta}$ since 2013		0.9	-0.8	0.0
$\boldsymbol{\gamma}$	**0.823**	**0.815**	**0.809**	**0.830**
% change in $\boldsymbol{\gamma}$ since 2013		-1.0	-1.7	0.9
S_K (% K-40/cps)	**0.00746**	**0.00748**	**0.00755**	**0.00763**
% change in S_K since 2013		0.3	1.2	2.2
S_U (ppm eU / cps)	**0.0877**	**0.0876**	**0.0876**	**0.0899**
% change in S_U since 2013		-0.1	-0.2	2.5
S_{Th} (ppm eTh / cps)	**0.157**	**0.156**	**0.157**	**0.155**
% change in S_{Th} since 2013		-0.3	-0.03	-1.2

Table B3: Calibration parameters for NGU (SN6039) spectrometer

Atomberedskap system (SN6039)			
	Calibration year		
	2021	2022	2023
$\boldsymbol{\alpha}$	**0.302**	**0.273**	**0.269**
% change in $\boldsymbol{\alpha}$ since 2022			-1.5
$\boldsymbol{\beta}$	**0.464**	**0.426**	**0.427**
% change in $\boldsymbol{\beta}$ since 2022			0.2
$\boldsymbol{\gamma}$	**0.795**	**0.771**	**0.763**
% change in $\boldsymbol{\gamma}$ since 2022			-1.0
S_K (% K-40/cps)	**0.0073**	**0.0073**	**0.0073**
% change in S_K since 2022			-0.1
S_U (ppm eU / cps)	**0.085**	**0.086**	**0.085**
% change in S_U since 2022			-1.0
S_{Th} (ppm eTh / cps)	**0.154**	**0.152**	**0.153**
% change in S_{Th} since 2022			0.7

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