

## Reference material set: VDZ500-VDZ524



### Calibration material set for trace element determination using XRF

The reference material set is used to calibrate X-ray fluorescence spectrometers on pressed pellet preparations with regard to the trace element content of cements and clinkers. It consists of 25 calibration samples comprising ground Portland cement clinker and cements with limestone, granulated blast furnace slag, oil shale, coal fly ash and natural pozzolans. One unit of the set consists of 25 samples with at least 125 g per cement or clinker.

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**Note: The materials offered are not formally certified reference materials (CRMs) as defined by ISO Guide 30.**

## 1 Product description

Material: 25 materials (clinker and cements)

Product code: VDZ500 to VDZ524

The reference material set is used to calibrate X-ray fluorescence spectrometers on pressed pellet preparations with regard to the trace element content of cements and clinkers. It consists of 25 calibration samples comprising ground Portland cement clinker and cements with limestone, granulated blast furnace slag, oil shale, coal fly ash and natural pozzolans. One unit of the set consists of 25 samples with at least 125 g per cement or clinker.

The methods for determining the reference values and informative values are given in **Table 1** and **Table 2** respectively. The reference values for the respective elements are given **Table 5**, **Table 6** and **Table 7** in Section 6. In addition, informative values are given in **Table 8**, **Table 9** and **Table 10** in Section 7, which can essentially be used for matrix correction in X-ray fluorescence analysis.

## 2 Methods for determining reference values and uncertainties

The reference values were determined using at least one traceable method. If several results were available, the reference value was calculated as the arithmetic mean of the individual values.

**Table 1** Methods for reference values

Elements	Methods	Calibration materials
V, Cr, Mn, Co, Zn, As, Rb, Sr, Sb, Ba	ICP-MS INAA	VDZ500, VDZ501, VDZ502, VDZ504, VDZ505, VDZ507, VDZ508, VDZ509, VDZ510, VDZ511, VDZ518, VDZ519
V, Cr, Mn, Co, Zn, As, Rb, Sr, Sb, Ba, Ni, Cu, Mo, Sn, Pb	ICP-MS	VDZ500 to VDZ524

**Table 2** Methods for informative values

Elements	Methods	Calibration materials
CO <sub>2</sub> , H <sub>2</sub> O	IR	VDZ500 bis VDZ524
SiO <sub>2</sub> , Al <sub>2</sub> O <sub>3</sub> , P <sub>2</sub> O <sub>5</sub> , SO <sub>3</sub> , MgO, CaO, TiO <sub>2</sub> , Fe <sub>2</sub> O <sub>3</sub> , K <sub>2</sub> O, Na <sub>2</sub> O	XRF	VDZ500 bis VDZ524
TiO <sub>2</sub> , Fe <sub>2</sub> O <sub>3</sub> , Cl, K <sub>2</sub> O, Na <sub>2</sub> O	XRF INAA	VDZ500, VDZ501, VDZ502, VDZ504, VDZ505, VDZ507, VDZ508, VDZ509, VDZ510, VDZ511, VDZ518, VDZ519
Tl, Cd	ICP-MS	VDZ500 bis VDZ524
Cl	EN 196-2	VDZ500 bis VDZ524

ICP-MS Inductively coupled plasma mass spectrometer, digestion EN 13656:2021

INAA Instrumental neutron activation analysis

IR thermal release at 950°C in inert gas flow without catalyst, infrared-detection

XRF wavelength dispersive XRF analysis on fused beads with lithium borates

EN 196-2 Determination of chloride according to Vollhard (EN 196-2)

The stated uncertainty takes into account proportions from possible material inhomogeneity as well as differences and uncertainties in the analytical methods used.

The standard deviation for all major, minor and most trace elements determined by X-ray fluorescence analysis was used as the uncertainty contribution for the homogeneity ( $u_{r,i}$ ) of element  $i$ .

$$u_{r,i} = \sqrt{\frac{1}{N_i - 1} \sum_{j=1}^N (x_j - \bar{x})^2} \quad \text{Equation 1}$$

where:

$u_{r,i}$  = Uncertainty contribution from homogeneity of samples

$N$  = Number of bottlings examined

$x_j$  = Observed value of the  $j^{\text{th}}$  measurement

$\bar{x}$  = arithmetic mean of the bottlings examined

For elements whose concentrations were predominantly  $<5 \mu\text{g/g}$ , the results for this element were not included in the assessment of homogeneity and no total uncertainty was reported for this element. These values are given as informative values.

For calibration samples and elements for which the reference values were based on several laboratories or methods, the reference value uncertainty ( $u_{R,i}$ ) was calculated according to **Equation 2**:

$$u_{R,i} = \frac{\sqrt{\frac{1}{M_i - 1} \sum_{j=1}^M (x_j - \bar{x})^2}}{\sqrt{M_i}} \quad \text{Equation 2}$$

where:

$u_{R,i}$  = reference value uncertainty

$M$  = number of laboratories or methods

$x_j$  = observation value of the  $j^{\text{th}}$  laboratories / method

$\bar{x}$  = arithmetic mean of the observation values from the various laboratories/ methods

If the result for an element  $i$  was based solely on the analysis of a single laboratory or method, the standard uncertainty reported by the laboratory for the corresponding element was used as the reference value uncertainty ( $u_{R,i}$ ).

The total uncertainty of the specified reference values was calculated taking into account both contributions and an expansion factor  $k = 1.96$  according to **Equation 3**, thus corresponding to an expanded measurement uncertainty with a confidence level of approximately 95%.

$$u_{total,i} = \sqrt{u_{r,i}^2 + u_{R,i}^2} * k \quad \text{Equation 3}$$

### 3 Description of the calibration ranges

The calibration range can be expressed by the minimum and maximum concentrations of the elements in the 25 calibration cements. This range is given in **Table 3**.

**Table 3** Calibration range for the XRF cement calibration

Parameter	Unit	Minimum	Maximum
CO <sub>2</sub>	mass%	0.09	7.63
H <sub>2</sub> O	mass%	0.18	3.74
Cl	mass%	<0.007	0.66
SiO <sub>2</sub>	mass%	18.6	32.9
Al <sub>2</sub> O <sub>3</sub>	mass%	2.99	10.3
TiO <sub>2</sub>	mass%	0.14	0.67
P <sub>2</sub> O <sub>5</sub>	mass%	0.04	0.43
Fe <sub>2</sub> O <sub>3</sub>	mass%	0.21	7.27
Mn <sub>2</sub> O <sub>3</sub>	mass%	0.02	1.43
MgO	mass%	0.69	7.29
CaO	mass%	38.5	66.5
SO <sub>3</sub>	mass%	0.41	4.82
K <sub>2</sub> O	mass%	0.35	3.19
Na <sub>2</sub> O	mass%	0.07	1.54
V	µg/g	28.2	173
Cr	µg/g	10.9	255
Mn	µg/g	155	9915
Co	µg/g	2.0	23.3
Ni	µg/g	12.4	82.6
Cu	µg/g	22	391
Zn	µg/g	36.8	2137
As	µg/g	1.34	111
Rb	µg/g	9.16	111
Sr	µg/g	278	3191
Mo	µg/g	0.41	45.7
Cd	µg/g	0.08	4.35
Sn	µg/g	0.48	72.5
Sb	µg/g	0.63	52.3
Ba	µg/g	120	1383
Tl	µg/g	<0.02	3.03
Pb	µg/g	4.61	117

#### 4 Overview of cement types in calibration

The overview of cement types is intended as a rough guide. Where necessary, the cement types have been translated into the European cement type system of EN 197-1 and EN 197-5 and presented in a simplified form. The main constituents contained in addition to clinker have been added in accordance with the abbreviations from EN 197-1, even if this is not customary in some cases according to the standard designations. The following abbreviations have been used: granulated blast furnace slag (S), limestone powder (LL), natural pozzolan (P), silica-rich fly ash (V), burnt oil shale (T) (for cements containing either P, V or T, all three component abbreviations P/V/T have been given).

**Table 4** Assignment of cement types to calibration samples

Calibration material	cement type
VDZ500	CEM I
VDZ501	CEM I
VDZ502	CEM II (S)
VDZ503	CEM II (S)
VDZ504	CEM I
VDZ505	CEM I
VDZ506	CEM I
VDZ507	CEM III (S)
VDZ508	CEM I
VDZ509	CEM II-M (LL, P/V/T)
VDZ510	CEM I
VDZ511	CEM III (S)
VDZ512	CEM III (S)
VDZ513	CEM III (S)
VDZ514	CEM I
VDZ515	CEM II-M (S, P/V/T)
VDZ516	CEM II (P/V/T)
VDZ517	CEM II-M (LL, P/V/T)
VDZ518	CEM IV (P/V/T)
VDZ519	CEM II (P/V/T)
VDZ520	CEM I
VDZ521	CEM II (LL)
VDZ522	CEM II (LL)
VDZ523	Clinker
VDZ524	Clinker

## 5 Instructions for use

The homogeneity of the samples was verified for standard sample quantities for tablet preparation (approx. 10 g per tablet). Homogeneity was not tested for smaller sample quantities.

The sample should be stored tightly sealed and protected from moisture. The storage temperature should not exceed  $(20 \pm 4)^\circ\text{C}$ .

After opening the sample, air humidity can be absorbed by the cement. Therefore, contact with air and moisture must be minimised. Drying the samples at  $105^\circ\text{C}$  is not recommended. If moisture or other contaminants are absorbed after the sample container is first opened, the validity of the specified reference values can no longer be guaranteed.

## 6 Reference values

**Table 5** Reference data for 25 calibration cements for the parameters vanadium (V), chromium (Cr), manganese (Mn), cobalt (Co), nickel (Ni) and copper (Cu)

Calibration material	Vanadium (V)	Chromium (Cr)	Manganese (Mn)	Cobalt (Co)	Nickel (Ni)	Copper (Cu)
Unit	mg/kg					
VDZ500	57.3 ± 4.8	104 ± 9	433 ± 21	12.1 ± 1.0	36.7 ± 4.2	291 ± 36
VDZ501	122 ± 9	118 ± 12	221 ± 26	8.89 ± 1.24	82.6 ± 8.9	39.8 ± 9.2
VDZ502	82.9 ± 8.2	57.0 ± 10.8	1042 ± 61	9.05 ± 1.56	37.9 ± 4.1	141 ± 18
VDZ503	41.9 ± 10.7	62.4 ± 17.2	752 ± 92	3.54 ± 0.80	21.8 ± 2.5	85.6 ± 11.7
VDZ504	95.1 ± 6.0	255 ± 23	4035 ± 261	6.69 ± 1.30	23.8 ± 3.3	82.6 ± 11.6
VDZ505	51.2 ± 4.2	43.8 ± 8.9	743 ± 112	23.3 ± 2.0	26.5 ± 3.3	85.2 ± 12.0
VDZ506	46.2 ± 12.1	10.9 ± 2.7	155 ± 53	2.74 ± 0.62	38.1 ± 4.3	22.0 ± 4.4
VDZ507	40.1 ± 2.1	82.3 ± 9.1	9915 ± 626	2.99 ± 0.07	16.2 ± 2.0	23.9 ± 6
VDZ508	86.0 ± 7.2	59.8 ± 13.8	555 ± 267	11.0 ± 1.4	44.7 ± 5.2	162 ± 20
VDZ509	61.3 ± 2.8	43.8 ± 6.6	321 ± 33	4.51 ± 0.33	26.7 ± 3.4	86.8 ± 1.01
VDZ510	45.2 ± 5.9	51.5 ± 13.0	262 ± 24	6.39 ± 1.6	23.5 ± 2.6	106 ± 14
VDZ511	173 ± 13	45.7 ± 5.9	962 ± 63	2.03 ± 0.22	12.4 ± 1.9	54.2 ± 7.0
VDZ512	77.6 ± 19.3	88.5 ± 24.4	1760 ± 207	3.23 ± 1.91	23.4 ± 3.5	48.5 ± 8.5
VDZ513	136 ± 33	56.5 ± 13.8	859 ± 101	2.78 ± 0.63	16.6 ± 1.7	93.3 ± 11.7
VDZ514	74.8 ± 18.5	61.6 ± 19.3	624 ± 75	10.5 ± 2.6	39.4 ± 4.3	160 ± 20
VDZ515	156 ± 38	60.5 ± 16.7	638 ± 76	9.41 ± 2.64	38.4 ± 4.2	77.8 ± 9.8
VDZ516	97.1 ± 24.0	78.9 ± 22.1	766 ± 91	9.40 ± 2.46	31.7 ± 3.5	91.2 ± 11.6
VDZ517	77.4 ± 19.1	63.9 ± 18.0	275 ± 38	11.5 ± 2.7	33.2 ± 3.5	93.8 ± 11.9
VDZ518	85.2 ± 7.3	82 ± 13.5	923 ± 66	9.90 ± 1.59	35.5 ± 4.4	103 ± 13
VDZ519	124 ± 7	67.5 ± 12.5	404 ± 20	18.7 ± 1.1	58.5 ± 6.2	82.4 ± 12.6
VDZ520	28.2 ± 7.6	123 ± 32	353 ± 49	8.18 ± 2.09	57.7 ± 6.3	391 ± 49
VDZ521	62.3 ± 15.5	81.2 ± 24.4	310 ± 37	6.83 ± 1.65	46.4 ± 5.1	122 ± 17
VDZ522	32.8 ± 8.9	41 ± 14.8	316 ± 39	5.09 ± 1.70	21.0 ± 2.7	67.5 ± 9.1
VDZ523	41.4 ± 10.5	61.7 ± 19.2	452 ± 58	5.08 ± 1.70	31.9 ± 3.8	133 ± 17
VDZ524	61.2 ± 15.4	116 ± 32	1710 ± 202	7.55 ± 2.14	41.3 ± 4.6	65.9 ± 8.7

**Table 6** Reference data for 25 calibration cements for the parameters zinc (Zn), arsenic (As), rubidium (Rb), strontium (Sr), molybdenum (Mo), tin (Sn)

Calibration material	Zinc (Zn)	Arsenic (As)	Rubidium (Rb)	Strontium (Sr)	Molybdenum (Mo)	Tin (Sn)
Unit	mg/kg					
VDZ500	2137 ± 8	111 ± 2	15.9 ± 3	778 ± 18	10.0 ± 0.9	3.08 ± 1.64
VDZ501	100 ± 7	4.18 ± 1.20	12.1 ± 1.9	1506 ± 86	3.12 ± 0.27	0.511 ± 0.125
VDZ502	359 ± 6	59.7 ± 1.5	71.2 ± 2.9	1620 ± 19	41.3 ± 1.1	6.95 ± 1.13
VDZ503	487 ± 34	2.81 ± 1.15	22.8 ± 1.8	1190 ± 179	2.08 ± 0.18	0.481 ± 1.275
VDZ504	370 ± 2	3.71 ± 1.25	24.2 ± 2.9	525 ± 17	6.30 ± 0.67	4.04 ± 0.92
VDZ505	166 ± 5	35.7 ± 1.5	27.7 ± 2.2	1727 ± 77	1.85 ± 0.16	3.92 ± 1.32
VDZ506	36.8 ± 5.4	1.34 ± 0.79	14.5 ± 2.8	278 ± 43	0.582 ± 0.075	1.54 ± 0.33
VDZ507	111 ± 9	1.87 ± 0.92	37.8 ± 2.3	920 ± 16	<0.001	3.13 ± 0.83
VDZ508	359 ± 6	72.8 ± 1.8	75.1 ± 3.2	1986 ± 77	45.7 ± 1.9	7.21 ± 0.99
VDZ509	127 ± 11	3.54 ± 0.7	111 ± 4	2151 ± 72	0.872 ± 0.075	4.38 ± 1.16
VDZ510	147 ± 5	5.60 ± 0.66	30.2 ± 1.8	3191 ± 96	1.89 ± 0.16	5.42 ± 0.98
VDZ511	55.8 ± 4.6	1.74 ± 0.54	30.5 ± 2.3	873 ± 14	0.406 ± 0.075	2.71 ± 0.36
VDZ512	61.4 ± 5.5	6.52 ± 1.79	30.0 ± 2.5	663 ± 101	0.933 ± 0.779	1.49 ± 1.50
VDZ513	109 ± 8	2.49 ± 0.29	21.7 ± 0.1	789 ± 118	1.28 ± 0.11	3.68 ± 0.28
VDZ514	347 ± 24	66.6 ± 7.7	55.8 ± 2.5	1820 ± 273	45.6 ± 3.9	6.94 ± 1.08
VDZ515	224 ± 16	8.97 ± 1.16	39.1 ± 2.0	960 ± 145	9.30 ± 0.79	3.62 ± 1.06
VDZ516	270 ± 19	4.78 ± 0.81	52.1 ± 1.1	2010 ± 302	1.04 ± 0.09	4.74 ± 1.04
VDZ517	251 ± 18	13.0 ± 2.0	47.0 ± 2.4	1230 ± 185	2.66 ± 0.38	11.2 ± 1.1
VDZ518	237 ± 4	48.5 ± 1.1	93.7 ± 2.3	1672 ± 162	28.8 ± 1.1	72.5 ± 5.5
VDZ519	251 ± 7	11.9 ± 0.5	38.3 ± 1.7	1283 ± 26	6.43 ± 0.77	23.4 ± 2.4
VDZ520	255 ± 18	5.36 ± 0.89	9.16 ± 2.14	1010 ± 152	5.80 ± 0.49	17.5 ± 2.0
VDZ521	83.1 ± 7.7	5.83 ± 1.88	14.7 ± 1.7	510 ± 78	3.23 ± 0.27	6.52 ± 1.28
VDZ522	281 ± 22	2.95 ± 0.60	26.4 ± 3.5	1160 ± 174	0.743 ± 0.075	27.3 ± 2.4
VDZ523	743 ± 52	4.19 ± 0.80	20.2 ± 2.3	1400 ± 210	2.59 ± 0.22	6.21 ± 1.11
VDZ524	204 ± 14	4.07 ± 0.71	24.4 ± 1.9	1150 ± 173	3.13 ± 0.27	3.81 ± 1.97

**Table 7** Reference data for 25 calibration cements for the parameters antimony (Sb), barium (Ba), lead (Pb)

Calibration material	Antimony (Sb)	Barium (Ba)	Lead (Pb)
Unit	mg/kg		
VDZ500	52.3 ± 1.8	213 ± 43	77.6 ± 7.2
VDZ501	0.631 ± 0.300	1383 ± 19	4.61 ± 3.33
VDZ502	5.28 ± 2.05	370 ± 14	114 ± 11
VDZ503	4.55 ± 1.64	522 ± 58	51.4 ± 5.9
VDZ504	6.89 ± 1.69	185 ± 5	14.8 ± 3.9
VDZ505	32.3 ± 1.7	204 ± 5	22.4 ± 4.8
VDZ506	3.05 ± 0.92	220 ± 24	24.0 ± 3.6
VDZ507	2.51 ± 1.1	651 ± 15	11.9 ± 3.2
VDZ508	6.52 ± 1.05	255 ± 9	117 ± 11
VDZ509	8.10 ± 1.27	154 ± 5	62.5 ± 5.8
VDZ510	5.30 ± 1.50	169 ± 10	29.9 ± 3.1
VDZ511	3.43 ± 1.08	770 ± 19	7.65 ± 1.37
VDZ512	1.26 ± 1.69	982 ± 108	16.4 ± 5.2
VDZ513	4.68 ± 0.28	553 ± 61	11.8 ± 1.1
VDZ514	5.95 ± 1.24	281 ± 31	36.4 ± 3.6
VDZ515	4.32 ± 1.28	394 ± 44	17.9 ± 2.0
VDZ516	6.31 ± 1.43	373 ± 41	9.39 ± 1.4
VDZ517	7.42 ± 1.19	299 ± 33	21.9 ± 2.2
VDZ518	3.78 ± 1.47	444 ± 13	33.6 ± 3.2
VDZ519	4.86 ± 2.26	1066 ± 30	22.7 ± 2.3
VDZ520	13.6 ± 1.8	181 ± 25	8.25 ± 1.43
VDZ521	10.7 ± 1.4	120 ± 17	8.07 ± 5.78
VDZ522	4.56 ± 2.09	653 ± 78	12.6 ± 1.3
VDZ523	6.69 ± 1.42	260 ± 35	70.1 ± 6.5
VDZ524	4.58 ± 1.04	285 ± 42	14.4 ± 1.8

## 7 Informative Values

**Table 8** Informative values for 25 calibration cements for the parameters carbon dioxide (CO<sub>2</sub>), water (H<sub>2</sub>O), silicon dioxide (SiO<sub>2</sub>), aluminium oxide (Al<sub>2</sub>O<sub>3</sub>), phosphor oxide (P<sub>2</sub>O<sub>5</sub>), sulfur expressed as (SO<sub>3</sub>)

Calibration material	CO <sub>2</sub>	H <sub>2</sub> O	SiO <sub>2</sub>	Al <sub>2</sub> O <sub>3</sub>	P <sub>2</sub> O <sub>5</sub>	SO <sub>3</sub>
Unit	mass%					
VDZ500	0.23	0.21	21.3 ± 0.4	4.01 ± 0.16	0.07 ± 0.01	2.81
VDZ501	0.92	1.05	20.7 ± 0.3	4.49 ± 0.17	0.43 ± 0.013	2.72
VDZ502	1.29	0.56	22.4 ± 0.3	6.60 ± 0.25	0.10 ± 0.009	3.49
VDZ503	0.41	0.44	25.5 ± 0.4	6.06 ± 0.23	0.11 ± 0.008	2.78
VDZ504	1.04	1.10	19.8 ± 0.3	3.71 ± 0.16	0.11 ± 0.01	3.59
VDZ505	2.03	0.72	19.4 ± 0.3	4.34 ± 0.17	0.09 ± 0.006	2.30
VDZ506	2.06	1.25	20.9 ± 0.3	4.48 ± 0.17	0.05 ± 0.008	3.03
VDZ507	2.33	0.87	27.9 ± 0.4	8.01 ± 0.32	0.06 ± 0.008	3.69
VDZ508	1.42	0.38	20.0 ± 0.4	5.69 ± 0.22	0.13 ± 0.01	2.93
VDZ509	2.02	0.37	20.1 ± 0.3	4.79 ± 0.18	0.15 ± 0.006	4.67
VDZ510	1.75	0.62	19.3 ± 0.4	4.43 ± 0.22	0.31 ± 0.012	3.28
VDZ511	1.04	0.21	30.9 ± 0.5	9.88 ± 0.38	0.08 ± 0.006	1.32
VDZ512	0.82	0.68	30.9 ± 0.5	9.36 ± 0.36	0.04 ± 0.01	3.54
VDZ513	1.06	0.27	29.4 ± 0.4	9.41 ± 0.35	0.08 ± 0.005	1.66
VDZ514	0.62	0.54	20.3 ± 0.3	5.87 ± 0.22	0.09 ± 0.01	3.73
VDZ515	2.06	0.69	26.8 ± 0.4	7.61 ± 0.29	0.21 ± 0.01	4.82
VDZ516	1.46	2.68	28.6 ± 0.4	8.35 ± 0.31	0.15 ± 0.008	2.75
VDZ517	5.73	0.59	22.5 ± 0.4	7.92 ± 0.31	0.18 ± 0.005	2.73
VDZ518	0.64	3.74	32.9 ± 0.5	10.3 ± 0.4	0.12 ± 0.009	3.17
VDZ519	0.78	0.35	31.0 ± 0.5	9.12 ± 0.34	0.28 ± 0.016	3.14
VDZ520	0.14	0.22	22.1 ± 0.3	3.78 ± 0.15	0.32 ± 0.009	0.71
VDZ521	3.95	0.49	19.1 ± 0.3	5.35 ± 0.21	0.22 ± 0.005	3.05
VDZ522	7.63	0.37	18.6 ± 0.3	2.99 ± 0.11	0.14 ± 0.012	3.60
VDZ523	0.09	0.18	22.4 ± 0.3	4.77 ± 0.19	0.16 ± 0.006	0.41
VDZ524	0.10	0.20	20.3 ± 0.3	5.66 ± 0.22	0.16 ± 0.011	0.68

**Table 9** Informative values for 25 calibration cements for the parameters Calcium oxide (CaO), Chloride (Cl), Potassium oxide (K<sub>2</sub>O), Sodium oxide (Na<sub>2</sub>O), Titanium dioxide (TiO<sub>2</sub>)

Calibration material	CaO	Cl	K <sub>2</sub> O	Na <sub>2</sub> O	TiO <sub>2</sub>
Unit	mass%				
VDZ500	63.0 ± 0.4	0.009 ± 0.001	0.563 ± 0.016	0.252 ± 0.039	0.219 ± 0.028
VDZ501	64.6 ± 0.5	0.007 ± 0.002	0.348 ± 0.016	0.107 ± 0.01	0.399 ± 0.028
VDZ502	56.8 ± 0.8	0.093 ± 0.010	1.62 ± 0.05	0.169 ± 0.012	0.362 ± 0.031
VDZ503	57.9 ± 0.5	0.031 ± 0.004	0.620 ± 0.056	0.25 ± 0.046	0.44 ± 0.012
VDZ504	61.1 ± 0.4	0.054 ± 0.002	0.677 ± 0.008	0.296 ± 0.003	0.251 ± 0.008
VDZ505	61.5 ± 0.3	0.019 ± 0.002	0.671 ± 0.01	0.132 ± 0.015	0.243 ± 0.02
VDZ506	66.3 ± 0.5	<0.007	0.620 ± 0.057	0.07 ± 0.015	0.14 ± 0.006
VDZ507	44.6 ± 0.5	<0.007	1.30 ± 0.02	0.311 ± 0.009	0.37 ± 0.012
VDZ508	61.2 ± 0.5	0.088 ± 0.010	1.70 ± 0.05	0.202 ± 0.011	0.257 ± 0.012
VDZ509	62.3 ± 0.2	0.656 ± 0.046	1.35 ± 0.15	0.291 ± 0.021	0.274 ± 0.019
VDZ510	63.6 ± 0.7	0.089 ± 0.011	0.951 ± 0.034	0.289 ± 0.01	0.23 ± 0.019
VDZ511	47.5 ± 0.6	0.065 ± 0.012	0.731 ± 0.03	0.384 ± 0.012	0.575 ± 0.014
VDZ512	45.6 ± 0.5	0.050 ± 0.007	0.770 ± 0.074	0.33 ± 0.059	0.67 ± 0.006
VDZ513	49.8 ± 0.4	0.057 ± 0.008	0.590 ± 0.053	0.36 ± 0.064	0.55 ± 0.005
VDZ514	60.9 ± 0.5	<0.007	1.51 ± 0.14	0.13 ± 0.026	0.27 ± 0.01
VDZ515	49.3 ± 0.4	0.030 ± 0.004	0.990 ± 0.092	0.300 ± 0.055	0.44 ± 0.009
VDZ516	47.1 ± 0.4	0.024 ± 0.003	1.79 ± 0.16	0.680 ± 0.120	0.47 ± 0.006
VDZ517	53.4 ± 0.6	0.084 ± 0.012	1.23 ± 0.12	0.270 ± 0.054	0.53 ± 0.005
VDZ518	37.6 ± 1.4	0.011 ± 0.003	3.19 ± 0.03	1.54 ± 0.07	0.371 ± 0.017
VDZ519	48.7 ± 0.5	0.020 ± 0.002	0.918 ± 0.017	0.354 ± 0.009	0.444 ± 0.033
VDZ520	61.9 ± 0.5	0.030 ± 0.004	0.510 ± 0.047	0.220 ± 0.041	0.22 ± 0.006
VDZ521	62.8 ± 0.6	0.059 ± 0.008	0.510 ± 0.047	0.090 ± 0.018	0.29 ± 0.005
VDZ522	63.6 ± 0.5	0.058 ± 0.028	0.560 ± 0.066	0.150 ± 0.027	0.17 ± 0.008
VDZ523	66.5 ± 0.5	0.024 ± 0.003	0.530 ± 0.05	0.240 ± 0.045	0.23 ± 0.008
VDZ524	64.7 ± 0.5	0.014 ± 0.002	0.720 ± 0.066	0.380 ± 0.069	0.29 ± 0.008

**Table 10** Informative values for 25 calibration cements for the parameters Iron oxide (Fe<sub>2</sub>O<sub>3</sub>), Magnesium oxide (MgO), Thallium (Tl), Cadmium (Cd)

Calibration material	Fe <sub>2</sub> O <sub>3</sub>	MgO	Tl	Cd
Unit	mass%		mg/kg	
VDZ500	4.64 ± 0.07	2.46 ± 0.04	<0.292	2.29
VDZ501	3.11 ± 0.08	0.875 ± 0.039	<0.144	0.49
VDZ502	2.65 ± 0.05	3.16 ± 0.14	3.03	1.12
VDZ503	2.36 ± 0.08	2.51 ± 0.14	0.10	<0.483
VDZ504	4.97 ± 0.14	3.06 ± 0.45	0.07	0.33
VDZ505	7.27 ± 0.18	0.861 ± 0.069	0.33	0.50
VDZ506	0.21 ± 0.099	0.69 ± 0.055	<0.028	0.19
VDZ507	2.14 ± 0.06	7.29 ± 0.2	0.04	0.49
VDZ508	2.6 ± 0.05	2.37 ± 0.17	1.98	1.03
VDZ509	1.96 ± 0.05	1.08 ± 0.05	1.78	4.35
VDZ510	2.12 ± 0.09	1.96 ± 0.09	0.31	0.39
VDZ511	0.944 ± 0.05	5.66 ± 0.18	0.10	0.32
VDZ512	1.31 ± 0.07	5.25 ± 0.29	<0.293	0.49
VDZ513	1.29 ± 0.04	4.88 ± 0.27	0.17	0.30
VDZ514	3.03 ± 0.12	2.65 ± 0.15	0.13	0.32
VDZ515	3.03 ± 0.1	3.13 ± 0.18	1.23	0.77
VDZ516	3.3 ± 0.11	1.7 ± 0.09	0.13	0.10
VDZ517	3.32 ± 0.11	1.26 ± 0.07	0.33	0.34
VDZ518	3.53 ± 0.07	1.96 ± 0.06	<0.296	0.27
VDZ519	3.17 ± 0.13	1.02 ± 0.14	0.69	0.54
VDZ520	5.41 ± 0.17	4.11 ± 0.23	<0.001	0.08
VDZ521	2.69 ± 0.09	1.27 ± 0.07	0.34	0.24
VDZ522	1.18 ± 0.08	0.89 ± 0.05	<0.292	0.16
VDZ523	3.15 ± 0.11	1.01 ± 0.07	<0.030	0.70
VDZ524	3.28 ± 0.11	3.09 ± 0.17	<0.029	0.57