



**International
Standard**

ISO 4349

**Solid recovered fuels —
Determination of the recycling
index for co-processing**

*Combustibles solides de récupération — Détermination de
l'indice de recyclage pour le cotraitement*

**First edition
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Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO document should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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This document was prepared by Technical Committee ISO/TC 300, *Solid recovered materials, including solid recovered fuels*, in collaboration with the European Committee for Standardization (CEN) Technical Committee CEN/TC 343, *Solid recovered materials, including solid recovered fuels*, in accordance with the Agreement on technical cooperation between ISO and CEN (Vienna Agreement).

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Introduction

When solid recovered fuels (SRFs) are co-processed mainly in the cement industry, simultaneous energy recovery and recycling of mineral components of waste material takes place because the ash is directly incorporated into the clinker. SRF co-processing therefore allows for the replacement of both mineral resources and fossil fuels.

SRF ashes contain various chemical components that are crucial raw materials for cement manufacturers, fulfil specific tasks in cement clinker production or represent clinker phases giving the clinker its specific properties. For example, a major part of SRF ashes from mixed municipal and commercial waste consists of the four main chemical components that are required for cement clinker production: Al_2O_3 , CaO , Fe_2O_3 and SiO_2 (see [Annex A](#)). Additionally, minor ash constituents include MgO and TiO_2 , both of which are present in or as clinker phases. K_2O and Na_2O are typical constituents of feldspars that are present in the clay used as a raw material for the process. SO_3 , which is also present in SRF ash, or another sulfate carrier is needed in order to convert these alkali oxides into alkali sulfates, a clinker phase that alters the clinker's chemical reactivity with water.

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Solid recovered fuels — Determination of the recycling index for co-processing

1 Scope

This document specifies the determination of the share of material recovery in the case of energy recovery (i.e. co-processing) of solid recovered fuels (SRFs), for example, in a cement kiln. This share, called the recycling index (R-index), is calculated on the basis of the ash content and the ash composition.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 3884:—¹⁾, *Solid recovered fuels — Methods for the determination of the content of elements (Al, Ca, Fe, K, Mg, Na, P, S, Si, Ti, As, Ba, Be, Cd, Co, Cr, Cu, Hg, Mo, Mn, Ni, Pb, Sb, Se, Sn, Th, V, Zn)*

ISO 11885, *Water quality — Determination of selected elements by inductively coupled plasma optical emission spectrometry (ICP-OES)*

ISO 21645, *Solid recovered fuels — Methods for sampling*

ISO 21646, *Solid recovered fuels — Sample preparation*

ISO 21656:2021, *Solid recovered fuels — Determination of ash content*

ISO 22940, *Solid recovered fuels — Determination of elemental composition by X-ray fluorescence*

EN 15309, *Characterization of waste and soil. Determination of elemental composition by X-ray fluorescence*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

- ISO Online browsing platform: available at <https://www.iso.org/obp>
- IEC Electropedia: available at <https://www.electropedia.org/>

3.1 recycling index

R-index

share of SRF that can be considered as recycled on a material level, expressed as a mass fraction in per cent of the dry matter

3.2 co-processing

use of SRF in manufacturing processes for energy recovery and simultaneously for material recovery of mineral components

1) Under preparation. Stage at the time of publication: ISO/DIS 3884:2024.

4 Symbols and abbreviated terms

A_{db}	ash content at 815 °C on a dry basis
Al_2O_3	aluminium(III) oxide
CaO	calcium oxide
(d)	dry (dry basis)
Fe_2O_3	iron(III) oxide
K_2O	potassium oxide
MgO	magnesium oxide
Na_2O	sodium oxide
SiO_2	silicon dioxide
SO_3	sulfur trioxide
TiO_2	titanium dioxide

5 Reagents

Use only reagents of recognized analytical grade and only distilled water or water of equivalent purity.

5.1 Water, e.g. deionized ($< 0,055 \mu S/cm$).

5.2 Nitric acid (HNO_3), approximately 15 mol/l, mass fraction of 65 % to 70 %.

5.3 Hydrofluoric acid (HF), approximately 23 mol/l, mass fraction of 40 % to 45 %.

5.4 Hydrochloric acid (HCl), approximately 12 mol/l, mass fraction of 35 % to 37 %.

5.5 Lithium metaborate ($LiBO_2$), solid.

5.6 Binder, solid or liquid, for example wax. Specifications are given in EN 15309.

6 Apparatus

The usual laboratory apparatus and, in particular, the following shall be used.

6.1 Analytical balance, with an accuracy of 1 mg or better.

6.2 Muffle furnace, for temperatures of 1 050 °C.

6.3 Inductively coupled plasma, normal commercial instrumentation with optical or mass spectrometric detector (ICP-OES, ICP-MS).

6.4 X-ray fluorescence spectrometer, an energy or wavelength dispersion system suitable for qualitative and (semi-)quantitative analysis of the elements listed in this document.

6.5 Microwave unit, in accordance with ISO 3884:—.

6.6 Press, in accordance with ISO 22940 or EN 15309.

6.7 Platinum crucible, e.g. Pt/Au5 %.

6.8 Inert bowl, for example made from porcelain, silicon dioxide or platinum with a depth of 10 mm to 20 mm and with a size selected in a way that the occupancy of the bottom area does not exceed 0,1 g/cm².

6.9 Magnetic stirrer, with heating function and PTFE (polytetrafluoroethylene) stirring bone.

6.10 Volumetric flasks, e.g. 250 ml.

7 Procedure

7.1 Preparation of the test sample

The sampling of SRF shall be carried out in accordance with ISO 21645 and the sample preparation in accordance with ISO 21646, with the final sample having a nominal top size of 1,0 mm or less. Hard impurities, i.e. inert materials or metals, that cannot be reduced in size with the apparatuses defined in ISO 21646 are sorted out during sample preparation and are not considered in the subsequent analysis steps. Their amount shall be documented. The sample is dried at 105 °C according to ISO 21660-3. Further procedures and analyses are carried out with the dried sample <1,0 mm free of hard impurities.

7.2 Determination of the ash content and preparation of ash sample

The determination of the ash content shall be carried out in accordance with ISO 21656:2021, method B. If the determination provides a sufficient amount of material to proceed with the analyses, the ashed material shall be used for subsequent analyses. If the determination of the ash content provides insufficient amounts of ash for the subsequent analysis steps (examples of ash content of typical constituents of SRF from mixed municipal and commercial waste are given in [Annex A](#)), the sufficient amount of ash shall be reached by using one or both of the following two approaches:

- a) The ashing process is repeated and the ashes are collected and united in order to reach the minimum amounts required for subsequent ash analyses. This may be the preferable approach for method A (wet digestion/ICP-MS, requiring approximately 200 mg of ash sample) and method B (fused beads/ICP-OES, requiring approximately 100 mg of ash sample).
- b) A correspondingly larger inert bowl is used and the amount of sample is increased accordingly, which may be the preferable option for pellet preparation and XRF analyses (method C, approximately 4,5 g to 10 g is required). The bowl shall fulfil the requirements defined by ISO 21656 and its size shall be selected in such a way that the occupancy of the bottom area does not exceed 0,1 g/cm².

7.3 Determination of the elemental content

The determination of the elemental content shall be carried out according to ISO 3884:— or ISO 22940. The element content shall be determined in the ashed sample.

7.4 Methods

7.4.1 Method A – wet digestion followed by ICP-MS or ICP-OES analysis

The ash shall be digested using microwave-assisted acid digestion with hydrochloric acid, nitric acid and hydrofluoric acid and analysed by ICP-MS or ICP-OES as described in ISO 3884:—.

7.4.2 Method B – preparation of fused beads followed by ICP-OES analysis

100 mg (± 20 mg) of the ashed sample shall be thoroughly mixed with 1 000 mg (± 10 mg) of the fluxing agent lithium metaborate in a platinum crucible. The mixture shall be melted in a muffle furnace at $1\,050\text{ }^{\circ}\text{C} \pm 10\text{ }^{\circ}\text{C}$ for 20 min. The resulting fused bead is allowed to cool down and dissolved incrementally by adding 80 ml of hydrochloric acid ($c = 2\text{ mol/l}$) into the crucible in small amounts. The dissolution shall be supported by heating (to approximately $60\text{ }^{\circ}\text{C}$) and stirring with a PTFE stirring bone. The digest solution shall be filled to a final volume of 250 ml with deionised water ($< 0,055\text{ }\mu\text{S/cm}$). This solution shall contain 0,4 g/l of the sample and 4 g/l of the fluxing agent. Only clear solutions shall be subjected to subsequent analyses, turbid digest solutions are discarded. A blank shall be prepared using the same method, but no sample is added. The element content in the digestion solutions shall be determined by ICP-OES in accordance with ISO 11885.

7.4.3 Method C – preparation of pellets followed by XRF analysis

The pellet preparation and XRF analyses shall be performed in accordance with ISO 22940 or EN 15309. The fine ash sample shall be mixed and homogenized with binder at a defined ratio (different ratios can be applied and the dilution factor needs to be considered; a typical sample to wax mass ratio is 10:1) and shall be pressed with an automatic or manual press. For a pellet with a diameter of 40 mm, about 10,0 g of the ash sample is required. For a pellet with a diameter of 32 mm, approximately 4,5 g ash sample is required.

7.4.4 Alternative procedures

Alternative methods can be applied if their performance is proved to be comparable with those listed in the preceding subclauses.

7.5 Calculation

7.5.1 Calculation of element oxides

The results for the concentrations of chemical elements need to be converted into concentrations of element oxides. The conversion is performed by multiplying the concentration of the respective element, expressed as mg/kg (d), with the corresponding conversion factor as shown in [Formula \(1\)](#):

$$c_{i_2} = F_{ci} * c_{i_1} \quad (1)$$

where

c_{i_1} is the concentration of a selected element expressed as mg/kg (d);

c_{i_2} is the concentration of the corresponding element oxide expressed as mg/kg (d), see [Table 1](#);

F_{ci} is the corresponding conversion factor as listed in [Table 1](#).

Table 1 — Conversion factors

Element	Element oxide	Conversion factor F_c
Al	Al_2O_3	1,889 4
Ca	CaO	1,399 2
Fe	Fe_2O_3	1,429 7
K	K_2O	1,204 6
Mg	MgO	1,658 3
Na	Na_2O	1,348 0
S	SO_3	2,496 9
Si	SiO_2	2,139 3
Ti	TiO_2	1,668 5

7.5.2 Calculation of R-index for co-processing

The share of the SRF that is recycled on a material level (i.e. R-index), expressed as mass fraction in per cent of the dry matter [% (d)], can either be calculated considering the four main chemical compounds required for the production of cement clinker (R_{i4}) or considering additional elements that are introduced by natural raw materials and are part of clinker phases as well (R_{i9}). The R-indices shall be calculated as follows:

$$R_{i4} = \frac{A_{db} * \frac{c_{Al_2O_3} + c_{CaO} + c_{Fe_2O_3} + c_{SiO_2}}{10\,000}}{100} \quad (2)$$

$$R_{i9} = \frac{A_{db} * \frac{c_{Al_2O_3} + c_{CaO} + c_{Fe_2O_3} + c_{K_2O} + c_{MgO} + c_{Na_2O} + c_{SO_3} + c_{SiO_2} + c_{TiO_2}}{10\,000}}{100} \quad (3)$$

where

A_{db} is the ash content of the general analysis sample at 815 °C on a dry basis, expressed as mass fraction in per cent of the dry matter;

c_x is the concentration of element oxides expressed as mg/kg (d).

8 Performance characteristics

Data for repeatability and reproducibility for predefined solid recovered fuel samples (paper fibre sludge, high calorific waste fraction from non-hazardous municipal solid waste) are shown in [Annex B](#).

9 Test report

The test report shall contain at least the following information:

- name, address and location of any laboratory involved in the analysis;
- description and identification of the laboratory sample;
- date of receipt of laboratory sample and date(s) of performance of test;
- a reference to this document, i.e. ISO 4349:2024;
- reference to the analytical standard used for the determination of each element;
- the analytical results for R-index₄ and/or R-index₉, referring to % (d);
- amount of hard impurities, referring to % (d);
- any details not specified in this document or which are optional, and any other factors which can have affected the results;
- unique identification of report (such as serial number) and of each page and total number of pages of the report.

The laboratory should keep a trace of any analytical steps and intermediate results (raw data and calculation details) that should be kept available in case of specific requirements.

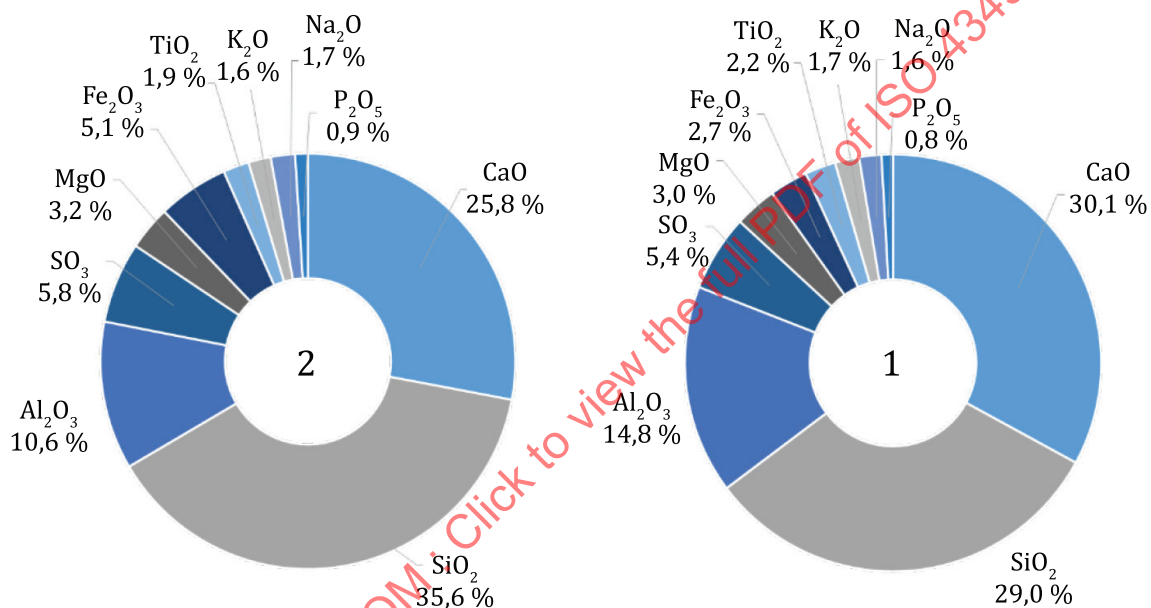
Annex A

(informative)

SRF ash composition from mixed municipal and commercial waste

Average ash composition (arithmetic means) of ashes of SRF for secondary firing (SRF “secondary” utilized, for example, in the calciner, $n = 30$) and SRF for primary firing (SRF “primary” utilized in the main burner, $n = 50$) from Austria, Croatia, Slovakia and Slovenia in mass per cent dry mass ($\text{wt}\%_{\text{DM}}$) is provided in [Figure A.1](#).

Comparison of ash composition of 80 investigated SRF samples from Austria, Croatia, Slovakia and Slovenia and their average values with other fuels and raw materials relevant to the cement industry is provided in [Figure A.2](#).

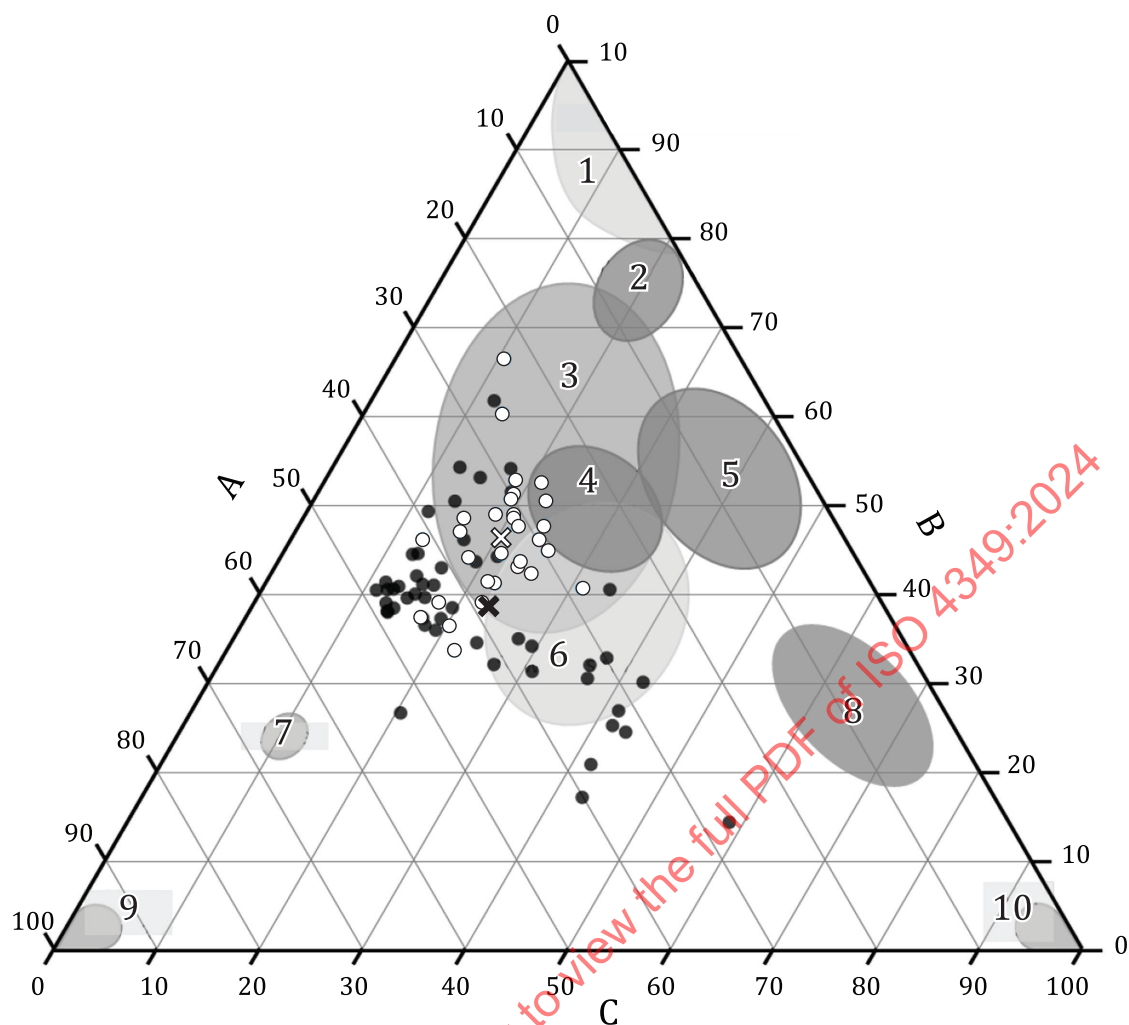


Key

- 1 SRF “secondary”
- 2 SRF “primary”

NOTE Percentages are not normalized to 100 %.

Figure A.1 — Average ash composition (arithmetic means) of ashes of SRF for secondary firing (SRF “secondary” utilized, for example, in the calciner, $n = 30$) and SRF for primary firing (SRF “primary” utilized in the main burner, $n = 50$) from Austria, Croatia, Slovakia and Slovenia in mass per cent dry mass ($\text{wt}\%_{\text{DM}}$)^[4]



Key

- SRF “secondary”
- SRF “primary”
- ⊗ average SRF “secondary”
- ⊗ average SRF “primary”

- A CaO [%]
- B SiO₂ [%]
- C Fe₂O₃+Al₂O₃ [%]
- 1 used foundry sand
- 2 fuller's earth
- 3 lignite coal
- 4 plastics/rubber/RDF
- 5 hard coal
- 6 sewage sludge
- 7 clinker
- 8 used tyres
- 9 lime sludge
- 10 mill scale

Figure A.2 — Comparison of ash composition of 80 investigated SRF samples from Austria, Croatia, Slovakia and Slovenia and their average values with other fuels and raw materials relevant to the cement industry^[4]

Ash composition, content and calculated R-index are given in [Tables A.1](#) and [A.2](#).

Table A.1 — Ash composition, ash content and calculated R-index of SRF “secondary” and “primary” from Austria, Croatia, Slovakia and Slovenia^[4]

SRF sample	Ash composition wt%, 950 °C									Sum of all meas- ured oxides	Ash 815 °C % _{DM}	Ash 950 °C % _{DM}	R-index ₄ , 950 °C	R-index ₉ , 950 °C
	CaO	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	SO ₃	MgO	Na ₂ O	K ₂ O	TiO ₂					
Secondary 1	26,6	33,7	6,6	5,0	5,6	3,1	2,8	2,7	4,5	92,2	15,7	15,6	11,2	14,1
Secondary 2	18,6	42,7	7,0	2,5	7,6	2,9	1,4	1,6	0,9	86,2	21,5	21,0	14,9	17,9
Secondary 3	22,1	38,1	11,2	3,0	6,7	3,0	1,9	1,7	1,8	90,2	13,4	14,0	10,4	12,5
Secondary 4	30,9	34,7	11,2	7,6	5,6	2,0	2,0	1,4	2,0	99,7	8,5	7,9	6,7	7,7
Secondary 5	21,8	36,4	10,4	3,3	6,4	3,0	1,9	1,5	2,2	88,9	12,9	12,5	9,0	10,9
Secondary 6	32,0	37,4	9,0	6,6	5,5	2,8	1,5	1,3	1,3	99,0	14,2	14,5	12,3	14,1
Secondary 7	22,9	35,9	13,1	2,1	5,6	2,3	2,4	2,0	2,2	89,4	11,0	10,4	7,7	9,2
Secondary 8	25,4	28,3	6,0	8,8	4,6	3,0	1,8	1,3	1,9	81,7	16,7	16,5	11,3	13,4
Secondary 9	26,5	26,5	11,6	3,5	6,8	2,8	1,0	1,1	0,9	81,2	21,6	21,3	14,5	17,2
Secondary 10	19,2	30,5	7,2	5,4	6,8	5,4	2,0	1,7	1,8	81,0	11,4	11,3	7,0	9,0
Secondary 11	22,0	31,5	12,1	12,1	7,5	3,3	0,6	0,5	2,9	93,1	13,2	12,1	9,4	11,2
Secondary 12	27,5	35,8	10,2	11,2	5,7	2,7	1,6	1,6	1,9	98,6	19,5	19,2	16,3	18,9
Secondary 13	20,7	38,0	9,8	3,5	9,2	2,9	2,3	1,8	1,4	90,3	16,1	16,3	11,7	14,6
Secondary 14	32,5	27,2	11,5	3,6	7,6	2,4	1,1	1,4	2,3	90,2	14,5	15,4	11,6	13,8
Secondary 15	23,6	36,5	12,2	6,9	8,8	2,5	1,4	1,4	2,4	96,4	18,4	18,4	14,6	17,6
Secondary 16	24,7	33,4	6,6	4,1	10,7	3,0	1,3	1,5	1,5	87,4	15,6	16,1	11,1	14,0
Secondary 17	36,6	27,8	14,0	4,3	3,8	2,7	1,1	0,7	2,1	94,9	13,4	13,2	10,9	12,3
Secondary 18	31,2	35,0	6,8	2,9	9,4	3,3	2,8	2,1	1,6	96,0	16,2	15,8	12,0	15,0
Secondary 19	22,1	33,4	15,2	3,9	3,4	2,5	2,4	2,0	1,3	87,0	17,0	17,2	12,9	14,8
Secondary 20	20,0	57,7	6,5	2,8	3,0	2,4	2,5	1,9	0,8	97,8	30,6	30,2	26,3	29,5
Secondary 21	33,2	27,1	7,3	5,1	6,6	3,5	1,9	1,7	3,5	90,6	12,3	12,8	9,3	11,5
Secondary 22	22,5	44,8	12,8	5,3	4,1	3,6	1,5	1,8	1,3	98,4	25,5	25,0	21,3	24,4
Secondary 23	27,9	36,1	11,7	5,6	5,8	3,8	1,9	1,9	1,2	96,4	27,8	27,0	22,0	25,9
Secondary 24	26,3	39,6	10,3	4,6	4,9	3,7	1,5	1,6	1,3	94,5	28,9	27,2	22,0	25,5
Secondary 25	27,5	42,0	12,4	6,4	3,5	3,3	1,9	1,7	2,0	101,6	24,6	24,1	21,3	24,3
Secondary 26	21,5	40,2	13,9	4,2	3,0	3,1	1,8	1,7	1,1	90,9	30,5	30,1	24,0	27,2
Secondary 27	25,0	41,8	16,0	4,9	3,5	4,0	1,4	1,6	1,5	100,4	23,4	23,2	20,4	23,1
Secondary 28	25,9	33,4	13,5	4,8	3,0	4,3	1,9	2,3	2,2	92,6	16,5	15,2	11,8	13,9
Secondary 29	26,4	35,0	13,9	5,0	4,6	3,5	1,4	1,8	1,9	94,4	16,9	16,2	13,0	15,1
Secondary 30	31,4	28,4	9,0	4,0	5,7	4,4	1,4	1,2	2,7	89,3	12,3	12,4	9,0	10,9
Primary 1	34,5	33,1	10,1	3,2	6,3	4,1	2,3	1,2	1,4	96,6	11,0	11,5	9,3	11,1
Primary 2	29,2	27,4	7,4	2,8	4,3	4,3	0,6	2,0	4,2	82,7	10,6	10,0	6,7	8,2
Primary 3	22,7	37,5	8,3	2,3	4,2	2,6	3,3	1,9	1,2	84,4	12,6	11,6	8,2	9,7
Primary 4	20,7	48,6	7,2	2,3	3,7	2,4	2,6	1,5	0,8	89,9	23,4	18,3	14,4	16,4
Primary 5	34,3	30,5	8,9	2,7	6,5	2,4	0,7	1,0	1,8	90,0	19,4	17,3	13,2	15,4
Primary 6	32,4	26,5	10,4	1,8	3,3	1,8	2,3	4,2	1,1	85,6	19,4	16,7	11,9	14,0
Primary 7	28,5	29,9	6,5	2,4	3,6	1,7	2,8	2,8	1,1	80,5	18,6	17,6	11,8	14,0
Primary 8	31,4	27,0	7,8	2,3	6,6	3,3	2,6	2,2	0,9	84,5	26,4	24,1	16,5	20,3
Primary 9	35,7	27,9	7,2	2,7	7,7	4,0	0,9	1,2	1,5	89,3	20,6	20,7	15,2	18,4
Primary 10	33,6	26,2	7,0	2,4	5,6	4,0	3,0	2,4	1,5	86,2	29,1	27,0	18,7	23,1
Primary 11	32,1	28,1	6,0	2,0	7,8	4,4	3,3	2,9	1,1	88,0	27,8	24,8	16,9	21,7
Primary 12	31,3	27,7	6,6	2,3	7,4	3,7	2,9	2,4	1,3	86,3	23,9	22,3	15,1	19,1
Primary 13	33,1	26,7	6,3	2,5	6,2	3,8	1,9	2,0	1,2	84,2	29,9	24,3	16,7	20,3
Primary 14	34,3	28,4	17,0	2,7	8,2	4,3	1,3	1,6	1,6	101,3	20,3	17,6	14,5	17,5

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Table A.1 (continued)

SRF sample	Ash composition wt%, 950 °C									Sum of all meas- ured oxides	Ash 815 °C % _{DM}	Ash 950 °C % _{DM}	R-index ₄ , 950 °C	R-index ₉ , 950 °C
	CaO	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	SO ₃	MgO	Na ₂ O	K ₂ O	TiO ₂					
Primary 15	32,9	27,9	7,6	6,8	7,6	3,3	1,3	1,7	2,7	92,6	22,2	22,1	16,6	20,3
Primary 16	26,3	30,7	10,5	3,1	5,8	5,4	1,5	1,9	1,5	88,9	28,2	26,8	18,9	23,2
Primary 17	29,4	37,2	6,7	2,2	8,5	3,8	3,8	2,8	1,4	96,5	17,5	17,4	13,1	16,7
Primary 18	36,9	29,4	11,1	3,3	9,1	3,1	0,9	1,3	1,9	97,4	19,4	19,1	15,4	18,5
Primary 19	30,3	12,8	31,0	1,3	3,4	1,7	0,5	0,6	4,5	86,7	16,0	16,1	12,1	13,9
Primary 20	25,6	32,5	11,3	4,2	6,3	7,1	1,7	2,5	1,4	95,8	24,3	23,1	17,0	21,4
Primary 21	20,6	10,8	43,4	1,0	2,6	1,0	0,4	0,3	2,0	82,4	12,7	12,7	9,6	10,4
Primary 22	36,4	29,1	13,2	2,3	6,0	3,0	1,4	1,6	2,0	95,7	12,7	12,8	10,4	12,2
Primary 23	31,5	33,0	9,7	2,9	6,5	3,1	1,1	1,2	2,0	91,3	20,9	20,6	15,9	18,7
Primary 24	37,4	32,4	7,8	2,5	6,1	3,3	1,7	1,6	1,1	94,3	18,0	17,8	14,2	16,7
Primary 25	26,4	20,0	34,2	1,4	4,0	1,2	0,5	0,7	3,3	92,1	14,5	14,6	12,0	13,4
Primary 26	37,1	35,5	9,5	2,6	6,5	3,1	1,0	1,3	2,0	99,1	18,8	17,9	15,2	17,6
Primary 27	32,5	30,3	23,2	0,9	3,6	0,7	0,4	0,4	2,0	94,1	29,4	29,4	25,6	27,6
Primary 28	28,1	34,9	8,1	4,6	4,8	3,0	1,2	1,2	2,3	88,7	21,4	21,5	16,3	19,0
Primary 29	36,4	32,6	10,8	2,6	0,6	0,3	1,0	1,2	1,9	88,0	17,0	16,4	13,5	14,3
Primary 30	33,3	18,5	35,9	1,4	4,0	1,9	0,7	0,9	4,2	101,0	14,9	14,3	12,7	14,4
Primary 31	32,3	25,1	17,6	3,4	4,1	2,4	1,5	1,2	4,1	93,2	8,0	8,1	6,4	7,4
Primary 32	29,5	24,3	21,1	2,9	3,2	2,2	1,1	1,2	4,4	91,0	8,5	8,5	6,6	7,6
Primary 33	25,7	28,1	30,2	2,0	2,3	1,6	1,8	1,7	3,0	97,5	11,4	11,4	9,8	11,0
Primary 34	21,3	33,4	26,0	2,1	2,0	1,5	3,0	2,5	2,6	95,3	13,3	13,0	10,8	12,3
Primary 35	32,0	29,1	11,6	3,3	4,8	2,4	1,8	1,7	1,8	89,6	15,2	13,4	10,2	11,9
Primary 36	22,2	31,1	5,7	2,9	9,2	5,4	0,9	1,0	1,4	80,6	21,1	21,0	13,0	16,8
Primary 37	24,4	39,6	6,5	2,6	6,4	2,6	2,2	2,0	0,8	87,7	30,8	28,7	21,0	25,0
Primary 38	26,0	21,9	31,7	2,4	2,7	2,1	1,0	1,3	4,8	94,6	8,3	8,6	7,0	8,1
Primary 39	27,0	27,0	28,0	2,6	2,6	2,3	1,2	0,8	6,4	98,8	10,5	10,2	8,6	10,0
Primary 40	23,5	25,4	31,4	4,5	2,3	2,2	1,3	1,6	4,9	97,8	9,0	9,0	7,6	8,7
Primary 41	25,4	23,5	23,9	4,4	2,0	2,3	1,0	10,3	0,6	94,1	9,0	8,9	6,9	8,3
Primary 42	31,4	29,3	23,4	2,0	2,5	1,8	1,6	1,4	2,3	96,6	9,4	9,3	8,0	8,9
Primary 43	27,5	20,8	32,5	2,1	2,7	2,6	0,8	0,7	1,6	92,3	7,1	7,2	6,0	6,6
Primary 44	35,8	29,8	5,6	2,7	8,6	5,1	0,9	1,0	1,4	91,5	23,4	24,0	17,7	21,8
Primary 45	34,6	29,5	6,5	2,4	10,0	4,3	1,1	1,1	1,6	91,9	23,3	20,8	15,2	18,9
Primary 46	32,1	33,2	7,4	2,1	8,2	3,6	1,3	1,3	1,4	91,1	25,9	26,1	19,5	23,6
Primary 47	33,8	27,1	7,6	2,2	10,7	3,7	1,5	1,5	1,4	90,1	25,9	25,8	18,3	23,1
Primary 48	41,0	20,5	8,7	7,1	5,8	2,5	1,0	0,6	2,9	91,4	9,6	9,3	7,2	8,4
Primary 49	23,6	40,6	12,7	2,2	6,5	4,3	2,0	1,8	2,3	96,4	19,6	18,8	14,9	18,0
Primary 50	21,1	39,9	10,6	2,3	7,6	4,0	2,2	1,3	2,4	91,6	29,6	29,0	21,4	26,5
Average secondary	25,8	35,6	10,6	5,1	5,8	3,2	1,7	1,6	1,9	92,3	18,0	17,7	13,9	16,2
Standard deviation secondary	4,6	6,5	2,9	2,3	2,0	0,7	0,5	0,4	0,8	5,6	6,1	5,9	5,4	1,2
RSD (%) secondary	17,8	18,1	27,1	46,1	35,1	22,5	29,9	26,6	42,1	6,1	33,8	33,3	38,8	88,3
Minimum	18,6	26,5	6,0	2,1	3,0	2,0	0,6	0,5	0,8	81,0	8,5	7,9	6,7	4,7
Median	25,7	35,4	11,2	4,7	5,7	3,0	1,8	1,7	1,9	92,4	16,4	16,2	11,9	14,8
80 th percentile	31,1	39,9	13,3	6,5	7,6	3,7	2,2	1,9	2,3	98,1	24,0	23,7	20,9	25,7
Maximum	36,6	57,7	16,0	12,1	10,7	5,4	2,8	2,7	4,5	101,6	30,6	30,2	26,3	44,8
Average primary	30,1	29,0	14,8	2,7	5,4	3,0	1,6	1,7	2,2	91,3	18,4	17,6	13,3	15,9
Standard deviation primary	5,1	6,7	10,2	1,2	2,4	1,3	0,9	1,4	1,3	5,2	6,9	6,4	4,5	2,0

Table A.1 (continued)

SRF sample	Ash composition wt%, 950 °C									Sum of all meas- ured oxides	Ash 815 °C % _{DM}	Ash 950 °C % _{DM}	R-index ₄ , 950 °C	R-index ₉ , 950 °C
	CaO	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	SO ₃	MgO	Na ₂ O	K ₂ O	TiO ₂					
RSD (%) primary	17,0	23,0	68,9	43,1	44,4	43,8	54,0	83,0	58,5	5,7	37,8	36,4	34,2	158,6
Minimum	20,6	10,8	5,6	0,9	0,6	0,3	0,4	0,3	0,6	80,5	7,1	7,2	6,0	2,9
Median	31,4	29,1	10,3	2,5	5,8	3,0	1,3	1,5	1,8	91,5	19,1	17,6	13,4	15,3
80 th percentile	34,4	33,2	25,0	3,2	7,7	4,1	2,3	2,1	3,0	96,5	25,1	24,1	16,8	27,7
Maximum	41,0	48,6	43,4	7,1	10,7	7,1	3,8	10,3	6,4	101,3	30,8	29,4	25,6	52,4
Average total	28,5	31,5	13,2	3,6	5,6	3,1	1,6	1,7	2,1	91,7	18,2	17,6	13,5	16,0
Standard deviation	5,3	7,3	8,5	2,1	2,3	1,1	0,7	1,2	1,1	5,4	6,6	6,2	4,8	1,8
RSD (%)	18,7	23,2	63,9	57,0	40,7	36,6	45,5	68,9	54,7	5,8	36,2	35,0	35,9	143,2
Minimum	18,6	10,8	5,6	0,9	0,6	0,3	0,4	0,3	0,6	80,5	7,1	7,2	6,0	2,7
Median	28,0	30,6	10,5	2,9	5,7	3,0	1,5	1,6	1,8	91,6	17,3	17,0	13,0	14,6
80 th percentile	33,3	36,9	16,5	4,9	7,6	4,0	2,3	2,0	2,7	96,6	24,5	24,1	17,0	26,6
Maximum	41,0	57,7	43,4	12,1	10,7	7,1	3,8	10,3	6,4	101,6	30,8	30,2	26,3	58,1
Limit of quantifi- cation	0,2	0,3	0,2	0,2	0,3	0,2	0,2	0,2	0,2					

Table A.2 — Ash composition, ash content and calculated R-index of SRF “primary” from Germany^[5]

SRF sample	Ash composition wt%, 815 °C									Sum of all meas- ured oxides	Ash 815 °C % _{DM}	Ash 950 °C % _{DM}	R-index ₄ , 815 °C	R-index ₉ , 815 °C
	CaO	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	SO ₃	MgO	Na ₂ O	K ₂ O	TiO ₂					
Primary 1	23,8	40,9	9,4	2,3	4,1	2,1	6,5	2,9	1,1	93,2	12,9	-	9,8	12,0
Primary 2	27,0	35,1	11,0	2,3	4,0	3,0	4,9	3,1	3,0	93,6	7,6	-	5,7	7,1
Primary 3	21,0	37,0	14,9	2,3	4,3	1,9	5,0	3,3	1,1	91,0	12,9	-	9,7	11,7
Primary 4	25,9	38,9	11,4	2,9	4,6	2,2	5,6	3,5	1,1	96,4	11,5	-	9,1	11,0
Primary 5	21,0	40,2	9,7	2,4	3,9	2,4	6,3	3,9	1,1	91,1	11,8	-	8,6	10,7
Primary 6	29,1	35,5	18,5	2,1	2,8	1,9	3,8	1,9	6,3	102,2	7,1	-	6,1	7,3
Primary 7	25,2	26,7	29,7	2,2	3,0	1,7	3,3	1,5	6,7	100,1	7,2	-	6,0	7,2
Primary 8	22,9	38,1	23,2	2,2	3,2	1,8	3,2	2,1	4,3	101,2	10,6	-	9,1	10,7
Primary 9	29,9	34,2	14,7	2,5	3,5	2,3	4,5	1,6	6,3	99,7	7,1	-	5,8	7,1
Primary 10	27,6	28,2	23,4	2,1	3,6	2,1	5,0	1,4	7,9	101,4	6,4	-	5,2	6,5
Primary 11	30,1	23,1	19,1	2,0	2,9	1,9	2,2	1,4	6,9	89,7	6,4	-	4,8	5,8
Primary 12	26,4	26,7	21,4	1,8	2,6	2,5	2,4	1,4	6,3	91,6	6,6	-	5,0	6,0
Primary 13	20,3	27,4	20,8	2,0	3,8	2,0	2,8	1,5	5,4	85,9	6,9	-	4,9	5,9
Primary 14	26,4	23,3	19,3	1,5	3,5	1,8	2,4	1,6	5,2	85,2	7,1	-	5,0	6,0
Primary 15	34,6	23,1	16,7	1,8	3,6	1,7	2,3	1,4	6,1	91,2	7,1	-	5,4	6,5
Primary 16	27,7	25,9	23,6	1,9	2,8	2,2	2,9	1,9	6,3	95,3	6,9	-	5,4	6,5
Primary 17	32,9	21,8	22,1	1,9	4,0	2,0	2,3	1,5	6,7	95,3	6,5	-	5,1	6,2
Primary 18	28,0	27,6	21,7	3,4	4,1	2,0	2,3	1,7	6,9	97,8	7,6	-	6,1	7,4
Primary 19	29,8	26,3	20,2	2,5	3,2	2,0	2,3	1,6	6,8	94,8	6,6	-	5,2	6,3
Primary 20	31,6	26,5	20,8	2,4	4,2	2,0	2,6	1,8	5,3	97,3	7,0	-	5,7	6,8
Primary 21	29,9	33,6	16,9	5,2	4,8	2,3	1,8	1,4	4,5	100,6	10,0	-	8,6	10,0
Primary 22	30,9	29,1	26,1	2,7	4,6	1,9	1,6	1,1	4,5	102,6	9,5	-	8,4	9,7
Primary 23	35,8	31,4	21,5	3,2	4,9	2,0	2,1	1,3	4,3	106,8	10,4	-	9,5	11,1
Primary 24	36,4	34,7	18,9	2,6	5,4	1,9	2,3	1,4	4,4	108,1	10,2	-	9,4	11,0
Primary 25	33,7	31,4	18,9	2,3	4,7	3,3	1,6	1,1	4,7	101,8	10,2	-	8,8	10,3
Primary 26	33,6	35,7	14,2	2,8	5,3	2,4	1,7	1,2	4,2	101,2	10,8	-	9,3	10,9
Primary 27	30,4	37,2	17,2	3,2	5,0	2,1	2,1	1,3	4,6	103,3	9,8	-	8,6	10,1
Primary 28	29,1	33,6	21,9	2,5	4,8	1,8	2,0	1,3	4,4	101,6	9,7	-	8,4	9,8

Table A.2 (continued)

SRF sample	Ash composition wt%, 815 °C									Sum of all meas- ured oxides	Ash 815 °C % _{DM}	Ash 950 °C % _{DM}	R-index ₄ , 815 °C	R-index ₉ , 815 °C
	CaO	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	SO ₃	MgO	Na ₂ O	K ₂ O	TiO ₂					
Primary 29	31,6	30,2	15,3	2,4	8,2	2,1	2,2	1,1	5,6	98,9	8,3	-	6,6	8,2
Primary 30	29,0	35,9	14,9	3,3	5,4	2,2	2,4	1,5	5,0	99,9	10,4	-	8,6	10,3
Primary 31	33,9	28,2	19,5	3,2	3,5	1,9	2,0	1,3	4,4	98,0	7,9	-	6,7	7,7
Primary 32	27,7	27,2	29,9	2,0	2,8	2,1	2,5	1,3	7,2	102,7	7,1	-	6,1	7,2
Primary 33	30,6	18,2	17,3	2,4	5,5	1,4	1,1	0,6	3,0	80,3	10,0	-	6,9	8,0
Primary 34	31,5	26,7	15,5	5,4	3,5	2,3	4,4	1,7	4,9	96,0	8,9	-	7,0	8,5
Primary 35	37,8	26,5	17,9	4,0	3,8	2,1	1,8	1,3	6,7	102,0	6,6	-	5,7	6,8
Primary 36	26,2	38,3	26,5	2,2	3,2	1,7	3,8	1,6	5,2	108,8	9,9	-	9,2	10,7
Primary 37	34,4	25,0	24,4	3,0	4,1	2,2	1,6	0,9	4,6	100,3	8,4	-	7,3	8,4
Primary 38	33,4	17,8	39,9	6,3	3,4	1,8	1,6	0,8	4,6	109,8	9,1	-	8,8	9,9
Primary 39	40,6	27,2	26,5	2,2	4,4	2,6	3,0	1,4	4,2	112,2	9,1	-	8,7	10,2
Primary 40	22,9	21,2	21,2	2,2	4,8	1,6	1,5	0,9	4,3	80,9	12,2	-	8,3	9,9
Primary 41	31,5	28,0	18,9	2,4	2,8	2,0	1,8	1,3	5,2	94,1	8,9	-	7,2	8,3
Primary 42	33,0	25,7	25,3	2,7	3,1	1,9	2,3	1,3	5,6	101,1	7,3	-	6,3	7,4
Primary 43	31,8	31,9	19,7	2,7	3,1	1,8	2,1	1,3	3,8	98,1	9,7	-	8,3	9,5
Primary 44	30,8	28,2	16,2	2,4	3,0	1,7	2,0	1,3	4,5	90,3	9,9	-	7,7	8,9
Primary 45	36,0	24,4	21,0	3,0	3,4	2,2	1,5	0,9	4,6	97,0	9,6	-	8,1	9,3
Primary 46	26,9	36,2	15,6	4,4	2,6	1,7	3,2	2,0	3,2	95,9	5,9	-	4,9	5,7
Primary 47	33,2	27,4	21,4	5,4	3,8	1,9	2,6	1,4	4,7	101,8	8,2	-	7,2	8,4
Primary 48	32,7	35,3	21,2	2,4	4,2	1,8	2,9	2,0	8,0	110,6	9,5	-	8,7	10,5
Primary 49	36,0	34,0	17,9	2,9	3,5	2,0	2,2	1,3	5,1	104,9	9,5	-	8,6	10,0
Primary 50	40,4	20,9	20,4	2,2	3,7	2,0	1,7	0,9	2,8	95,2	9,5	-	8,0	9,1
Average primary	30,3	29,8	19,9	2,8	3,9	2,0	2,8	1,6	4,9	98,0	8,8	-	7,3	8,6
Standard deviation primary	4,7	5,9	5,4	1,0	1,0	0,3	1,3	0,7	1,6	7,0	1,8	-	1,6	1,8
RSD (%) primary	15,5	19,7	27,2	36,5	25,5	16,1	46,5	43,0	33,9	7,1	20,6	-	22,0	21,3
Minimum	20,3	17,8	9,4	1,5	2,6	1,4	1,1	0,6	1,1	80,3	5,9	-	4,8	5,7
Median	30,5	28,2	19,6	2,4	3,8	2,0	2,3	1,4	4,7	98,5	9,0	-	7,3	8,5
80 th percentile	33,7	35,6	23,3	3,2	4,7	2,2	3,4	1,8	6,3	102,3	10,2	-	8,7	10,4
Maximum	40,6	40,9	39,9	6,3	8,2	3,3	6,5	3,9	8,0	112,2	12,9	-	9,8	12,0
Limit of quantifica- tion	0,2	0,3	0,2	0,2	0,3	0,2	0,2	0,2	0,2					

Total inorganic carbon content (TIC) and ash content for different ash samples are given in [Table A.3](#).

Table A.3 — Total inorganic carbon content (TIC) and ash content for different ash samples in relation to the incineration temperature^[6]

SRF sample	TIC ash residue 550 °C wt%	TIC ash residue 815 °C wt%	TIC ash residue 950 °C wt%	Ash content 550 °C wt%	Ash content 815 °C wt%	Ash content 950 °C wt%
Primary 1	3,1	0,3	0,1	12,3	11,0	11,5
Primary 3	4,4	0,2	0,2	15,8	12,6	11,6
Primary 4	3,3	0,6	0,4	25,5	23,4	18,3
Primary 5	4,0	0,3	0,4	22,1	19,4	17,3
Primary 6	4,5	0,7	0,6	26,3	19,4	16,7
Primary 7	4,0	0,7	0,5	22,2	18,6	17,6
Primary 19	4,3	0,7	< 0,1	17,5	16,0	16,1

Table A.3 (continued)

SRF sample	TIC ash residue 550 °C wt%	TIC ash residue 815 °C wt%	TIC ash residue 950 °C wt%	Ash content 550 °C wt%	Ash content 815 °C wt%	Ash content 950 °C wt%
Primary 20	2,7	0,6	0,4	25,3	24,3	23,1
Primary 22	3,9	0,5	0,3	14,9	12,7	12,8
Primary 27	5,5	0,5	0,4	36,0	29,4	29,4
Primary 32	4,1	0,6	0,4	9,7	8,5	8,5
Primary 36	3,8	0,2	0,1	29,1	21,1	21,0
Primary 40	1,7	0,2	< 0,1	9,8	9,0	9,0
Primary 41	2,1	0,7	0,5	9,9	9,0	8,9
Primary 44	4,0	0,5	0,4	27,5	23,4	24,0
Secondary 17	3,1	0,4	0,5	15,2	13,4	13,2
Secondary 18	2,0	0,1	0,1	19,9	16,2	15,8
Secondary 19	4,0	0,6	0,8	18,9	17,0	17,2
Secondary 20	3,3	0,2	0,2	31,7	30,6	30,2
Secondary 21	1,7	0,2	0,1	16,1	12,3	12,8
Secondary 24	1,7	0,3	0,3	32,9	28,9	27,2
Secondary 28	4,1	0,6	0,4	19,2	16,5	15,2

Ash content and element composition of selected material fractions of SRF “primary” from mixed commercial and municipal waste are given in [Table A.4](#).

Table A.4 — Ash content and element composition of selected material fractions of SRF “primary” from mixed commercial and municipal waste^[7]

SRF sample no.	Sorted material frac- tion	Ash (815 °C)	Al	Ca	Fe	K	Mg	Na	S	Si	Ti
		% _{DM}	mg/kg _{DM}	mg/kg _{DM}	mg/kg _{DM}	mg/kg _{DM}	mg/kg _{DM}	mg/kg _{DM}	mg/kg _{DM}	mg/kg _{DM}	mg/kg _{DM}
1	Sorting residue	16,64	54 900	251 000	50 400	12 000	27 500	15 000	37 400	120 000	8 660
2	Sorting residue	16,68	50 500	242 000	39 500	14 500	28 100	18 800	47 600	139 000	10 200
3	Sorting residue	11,53	54 300	220 000	47 000	12 900	22 500	15 900	31 600	142 000	13 200
4	Sorting residue	16,88	47 300	244 000	41 200	15 200	28 700	20 300	39 900	128 000	10 700
5	Sorting residue	15,78	50 700	242 000	49 400	12 200	27 500	15 300	29 000	127 000	9 280
6	Sorting residue	11,64	51 300	217 000	45 500	12 300	20 700	14 800	19 400	123 000	12 000
7	Sorting residue	11,74	49 900	219 000	45 600	12 400	22 400	17 600	27 800	143 000	12 900
8	Sorting residue	11,53	48 800	213 000	45 500	13 700	21 700	15 600	33 200	137 000	12 800
9	Sorting residue	16,22	53 600	263 000	44 600	13 500	28 600	17 400	40 100	131 000	11 400
10	Sorting residue	11,50	49 100	212 000	44 300	14 100	22 000	16 700	29 800	136 000	12 500
Average: sorting res- idue		14,01	51 040	232 300	45 300	13 280	24 970	16 740	33 580	132 600	11 364
Standard deviation		2,57	2 508	18 148	3 297	1 093	3 336	1 794	7 940	7 989	1 596
1	Wood	2,94	33 400	168 000	47 300	29 900	20 800	46 900	29 000	145 000	21 800
2	Wood	1,24	25 300	195 000	31 100	65 100	28 000	67 100	37 200	47 100	34 100
3	Wood	7,58	18 200	450 000	8 800	4 500	17 100	6 560	14 600	69 000	20 200
4	Wood	2,06	30 000	263 000	51 500	42 300	27 300	42 000	28 900	88 600	54 400
5	Wood	2,63	20 300	377 000	14 400	8 120	27 200	15 500	22 700	65 100	20 000
6	Wood	1,43	24 900	163 000	18 100	29 900	16 300	42 200	16 800	87 700	14 800
7	Wood	3,70	42 300	153 000	24 100	48 100	27 800	57 700	21 600	171 000	25 600
8	Wood	1,81	28 200	132 000	17 700	38 000	17 400	47 100	21 300	91 300	49 700
9	Wood	1,68	51 000	196 000	22 400	59 500	27 900	67 900	28 300	118 000	33 800
10	Wood	5,39	10 800	478 000	8 650	8 990	18 400	4 990	16 800	49 900	7 170
Average: wood		3,05	28 440	257 500	24 405	33 441	22 820	39 795	23 720	93 270	28 157

Table A.4 (continued)

SRF sample no.	Sorted material fraction	Ash (815 °C)	Al	Ca	Fe	K	Mg	Na	S	Si	Ti
		% _{DM}	mg/kg _{DM}	mg/kg _{DM}	mg/kg _{DM}	mg/kg _{DM}	mg/kg _{DM}	mg/kg _{DM}	mg/kg _{DM}	mg/kg _{DM}	mg/kg _{DM}
	Standard deviation	2,02	11 704	129 652	14 847	21 336	5 217	23 278	7 053	40 526	14 965
1	Composites	24,33	66 800	217 000	30 000	6 390	18 400	8 060	19 800	143 000	7 640
2	Composites	28,70	69 900	148 000	15 700	2 650	52 000	7 010	17 600	100 000	5 590
3	Composites	14,58	238 000	131 000	33 600	14 000	14 500	48 700	13 600	116 000	6 530
4	Composites	26,48	55 400	197 000	14 500	10 700	35 200	12 300	20 300	200 000	6 230
5	Composites	24,38	50 700	228 000	13 500	7 040	28 800	10 700	19 600	174 000	5 570
6	Composites	15,01	330 000	179 000	8 200	4 540	7 960	6 560	10 800	70 200	8 330
7	Composites	14,01	226 000	199 000	17 800	12 000	12 500	22 800	16 600	140 000	7 940
8	Composites	19,92	201 000	54 100	8 350	10 500	6 560	8 820	8 000	235 000	17 400
9	Composites	21,01	68 500	165 000	17 800	7 330	116 000	9 360	20 700	114 000	14 400
10	Composites	13,05	274 000	189 000	4 790	4 390	4 000	8 040	22 900	47 900	7 350
	Average: composites	20,15	158 030	170 710	16 424	7 954	29 592	14 235	16 990	134 010	8 698
	Standard deviation	5,72	106 480	50 599	9 214	3 698	33 828	12 988	4 779	57 385	3 974
1	Textiles	11,46	33 500	299 000	50 100	9 580	25 400	14 000	38 500	105 000	10 300
2	Textiles	16,48	51 400	187 000	88 700	17 600	23 900	19 100	36 800	165 000	8 090
3	Textiles	11,68	43 800	262 000	35 700	21 800	29 300	61 400	34 600	140 000	9 550
4	Textiles	14,55	42 900	313 000	36 500	11 000	25 500	10 900	41 900	101 000	9 210
5	Textiles	13,64	38 900	306 000	40 600	8 600	24 000	11 000	35 800	96 800	7 300
6	Textiles	13,45	64 600	250 000	35 000	20 600	14 900	16 600	32 800	130 000	13 700
7	Textiles	10,79	43 800	269 000	50 800	12 700	26 100	20 500	37 200	109 000	10 500
8	Textiles	10,22	55 500	188 000	39 200	26 100	26 000	22 600	24 200	159 000	11 300
9	Textiles	8,92	45 300	232 000	33 600	15 100	27 300	23 100	49 000	126 000	11 700
10	Textiles	11,29	35 100	264 000	27 000	5 460	19 800	6 300	27 300	101 000	13 800
	Average: textiles	12,25	45 480	257 000	43 720	14 854	24 220	20 550	35 810	123 280	10 545
	Standard deviation	2,26	9 475	44 540	17 380	6 583	4 104	15 375	6 984	24 901	2 156
1	Plastics	12,00	44 900	258 000	41 100	8 910	31 200	13 800	33 400	119 000	14 900
2	Plastics	11,64	59 000	260 000	24 100	6 690	28 000	10 100	30 300	136 000	20 100
3	Plastics	8,36	68 600	227 000	31 800	7 460	21 800	7 890	25 600	131 000	25 200
4	Plastics	10,46	27 600	236 000	66 800	5 470	22 700	6 270	36 900	140 000	20 400
5	Plastics	11,23	59 300	257 000	31 100	8 790	26 000	12 900	36 100	122 000	21 100
6	Plastics	8,33	63 600	228 000	31 200	7 280	19 600	8 080	30 000	114 000	24 500
7	Plastics	8,26	64 800	225 000	35 000	6 630	20 000	7 760	18 600	125 000	30 200
8	Plastics	8,30	68 000	225 000	30 500	8 650	20 300	8 790	23 500	126 000	24 800
9	Plastics	12,83	46 000	244 000	21 700	6 910	26 500	11 300	40 400	133 000	18 600
10	Plastics	8,20	66 800	228 000	32 900	8 300	19 400	8 670	24 400	125 000	25 300
	Average: plastics	9,96	56 860	238 800	34 620	7 509	23 550	9 556	29 920	127 100	22 510
	Standard deviation	1,86	13 320	14 673	12 504	1 133	4 120	2 424	6 892	7 951	4 331
1	Paper and cardboard	13,28	39 600	258 000	24 800	9 580	14 800	19 900	20 400	82 400	3 720
2	Paper and cardboard	12,23	67 500	336 000	27 000	13 200	18 300	23 300	21 800	109 000	7 920
3	Paper and cardboard	12,47	59 400	300 000	19 700	13 500	23 900	35 100	27 300	111 000	3 980
4	Paper and cardboard	13,30	63 800	286 000	37 900	15 100	19 400	21 400	24 100	109 000	4 210
5	Paper and cardboard	12,57	61 000	303 000	39 400	15 800	19 700	24 400	25 900	116 000	6 870
6	Paper and cardboard	12,80	78 400	333 000	9 530	11 100	14 400	14 100	18 400	104 000	5 430
7	Paper and cardboard	13,09	94 600	279 000	26 100	11 900	20 200	19 700	17 800	110 000	7 310
8	Paper and cardboard	12,18	75 900	332 000	18 800	9 210	22 500	18 500	23 600	104 000	6 970
9	Paper and cardboard	12,90	51 900	356 000	12 900	15 500	19 500	23 100	28 600	91 000	4 380
10	Paper and cardboard	13,46	68 500	343 000	12 100	13 500	24 700	17 800	28 200	90 400	4 150

Table A.4 (continued)

SRF sample no.	Sorted material frac- tion	Ash (815 °C)	Al	Ca	Fe	K	Mg	Na	S	Si	Ti
		% _{DM}	mg/kg _{DM}	mg/kg _{DM}	mg/kg _{DM}	mg/kg _{DM}	mg/kg _{DM}	mg/kg _{DM}	mg/kg _{DM}	mg/kg _{DM}	mg/kg _{DM}
	Average: paper and cardboard	12,83	66 060	312 600	22 823	12 839	19 740	21 730	23 610	102 680	5 494
	Standard deviation	0,46	15 083	32 001	10 276	2 349	3 414	5 597	3 938	10 965	1 612
1	Fines < 10 mm	23,38	37 200	175 000	50 100	13 800	37 000	39 400	16 900	200 000	3 340
2	Fines < 10 mm	23,50	38 600	170 000	81 500	12 800	28 100	18 400	18 300	157 000	6 920
3	Fines < 10 mm	23,75	52 100	175 000	65 300	17 500	21 100	36 500	14 500	185 000	6 280
4	Fines < 10 mm	22,03	49 900	171 000	41 200	17 000	26 000	19 000	22 300	175 000	6 850
5	Fines < 10 mm	20,54	43 900	187 000	48 100	16 200	24 500	17 500	25 200	183 000	6 570
6	Fines < 10 mm	20,69	45 200	191 000	44 000	15 800	25 200	16 600	25 100	187 000	7 650
7	Fines < 10 mm	20,63	42 000	188 000	37 100	15 300	25 400	17 000	25 700	190 000	7 060
8	Fines < 10 mm	23,31	58 300	180 000	42 700	16 900	23 200	33 500	18 300	195 000	6 390
9	Fines < 10 mm	20,41	46 700	208 000	48 900	15 800	22 500	16 000	26 300	176 000	7 340
10	Fines < 10 mm	21,40	52 000	199 000	37 900	17 800	28 200	17 200	26 500	186 000	7 430
	Average: fines < 10 mm	21,96	46 590	184 400	49 680	15 890	26 120	23 110	21 910	183 400	6 583
	Standard deviation	1,40	6 583	12 545	13 783	1 594	4 440	9 359	4 496	12 011	1 224

Annex B (informative)

Validation

An interlaboratory comparison study on the determination of the R-index for co-processing of SRFs was organized by Umweltbundesamt Austria in 2022 (SRF22ERI)^[8] and 31 participants from 14 countries registered (AT, BE, CH, DE, ES, FR, HU, IT, JP, KR, NL, PL, SK, UK) (sample dispatch: 12th September 2022; closing date for the submission of results: 27th October 2022; extension to 2nd November 2022 at the latest).

For validation, two real samples of SRF were selected and distributed to the registered participants. The sampling of SRF according to ISO 21645 was carried out by Montanuniversität Leoben. Sample preparation and homogenization (see ISO 21646) and homogeneity testing was performed jointly by Montanuniversität Leoben and Umweltbundesamt Austria as follows:

- SRF1R: paper fibre sludge (1 bag $\approx$ 0,4 kg per sample SRF1R, particle size: < 1 mm).
- SRF4R: high-calorific waste fraction from nonhazardous municipal solid waste (1 bag $\approx$ 0,9 kg per sample SRF4R, particle size: < 1 mm).
- SRF4R ash: ashed SRF of high-calorific waste fraction from nonhazardous municipal solid waste (portions of 1,0 g of homogenized ash of SRF4R for digestion or portions of 7,5 g of ashed SRF4R for XRF-application).

All provided samples for the validation were real samples and contained the elements of interest as they occur in their original composition – no spiking was performed.

The participants were advised to follow the procedures according to this document. Four independent determinations per sample and method (e.g. for method A, method B, method C) had to be carried out. Two independent determinations for calculation of dry mass and ash content were recommended. In cases of XRF analysis, two independent determinations were requested (e.g. preparation of two pellets or fused glass discs and duplicate analysis).

Statistical data evaluation was performed according to ISO 5725-2.^[1] For the statistical evaluation, all results per each method were treated separately. All data sets were tested for outliers by Grubbs test, Hampel test and Cochran test (see ISO 5725-2) and, after a plausibility check, technically confirmed outliers were eliminated for further statistical treatment.

The statistical data of results for each method are presented in [Tables B.1](#) to [B.12](#).

Table B.1 — Performance data for sample SRF1R method A (SRF1RA)

Sample	Method	Sample code	Parameter	Unit	<i>l</i>	<i>n</i>	<i>o</i> %	Mean (ref)	Mean	Recovery rate %	<i>s_R</i>	<i>C_{V,R}</i> %	<i>s_r</i>	<i>C_{V,r}</i> %
SRF1R	A	SRF1RA	A_DB	%(d)	10	27	10		25		1,1	4,4	0,274	1,1
SRF1R	A	SRF1RA	AL2O3ASH	mg/kg(d)	9	34	15		83 300		8 780	10,5	2 550	3,1
SRF1R	A	SRF1RA	ALASH	mg/kg(d)	9	34	15	45 258	44 100	97	4 640	10,5	1 350	3,1
SRF1R	A	SRF1RA	CAASH	mg/kg(d)	8	30	25	491 350	446 000	91	38 800	8,7	11 100	2,5
SRF1R	A	SRF1RA	CAOASH	mg/kg(d)	8	30	25		620 000		52 800	8,5	15 600	2,5
SRF1R	A	SRF1RA	DM	%	11	28	0	99,2	96,8	98	0,904	0,9	0,25	0,3
SRF1R	A	SRF1RA	FE2O3ASH	mg/kg(d)	9	33	15		12 600		1 150	9,1	935	7,4
SRF1R	A	SRF1RA	FEASH	mg/kg(d)	9	33	15	8 692	8 800	101	803	9,1	653	7,4
SRF1R	A	SRF1RA	K2OASH	mg/kg(d)	8	29	28		3 840		584	15,2	330	8,6
SRF1R	A	SRF1RA	KASH	mg/kg(d)	8	29	28	3 529	3 190	90	484	15,2	274	8,6
SRF1R	A	SRF1RA	MGASH	mg/kg(d)	8	30	25	12 476	12 400	99	1 050	8,4	219	1,8
SRF1R	A	SRF1RA	MGOASH	mg/kg(d)	8	30	25		20 600		1 730	8,4	363	1,8
SRF1R	A	SRF1RA	NA2OASH	mg/kg(d)	7	26	35		4 540		690	15,2	444	9,8
SRF1R	A	SRF1RA	NAASH	mg/kg(d)	7	26	35	3 346	3 360	100	512	15,2	329	9,8
SRF1R	A	SRF1RA	R-INDEX4	%(d)	7	24	37		23,2		1,73	7,5	0,544	2,3
SRF1R	A	SRF1RA	R-INDEX9	%(d)	7	23	39		24,5		1,72	7,0	0,577	2,4
SRF1R	A	SRF1RA	SASH	mg/kg(d)	5	18	50	4 332	4 650	107	923	19,8	525	11,3
SRF1R	A	SRF1RA	SIASH	mg/kg(d)	7	26	28	90 201	86 900	96	6 890	7,9	3 890	4,5
SRF1R	A	SRF1RA	SiO2ASH	mg/kg(d)	7	26	28		186 000		14 700	7,9	8 330	4,5
SRF1R	A	SRF1RA	SO3ASH	mg/kg(d)	5	18	50		11 600		2 300	19,8	1 310	11,3
SRF1R	A	SRF1RA	TiO2ASH	mg/kg(d)	8	29	26		5 610		607	10,8	261	4,6
SRF1R	A	SRF1RA	TIASH	mg/kg(d)	8	29	26	3 144	3 360	107	364	10,8	156	4,7

Key

l number of laboratories after outlier rejection

n number of individual test results after outlier rejection

o percentage of outliers

Mean (ref) mean value (reference laboratories)

Mean overall mean of results (without outliers)

s_R reproducibility standard deviation

C_{V,R} coefficient of variation of reproducibility

s_r repeatability standard deviation

C_{V,r} coefficient of variation of repeatability

Table B.2 — Performance data for sample SRF1R method B (SRF1RB)

Sample	Method	Sample code	Parameter	Unit	<i>l</i>	<i>n</i>	<i>o</i> %	Mean (ref)	Mean	Recovery rate %	<i>s_R</i>	<i>C_{V,R}</i> %	<i>s_r</i>	<i>C_{V,r}</i> %
SRF1R	B	SRF1RB	A_DB	%(d)	6	13	13		24,6		0,433	1,8	0,283	1,1
SRF1R	B	SRF1RB	AL2O3ASH	mg/kg(d)	6	20	20		81 800		2 840	3,5	2 410	2,9
SRF1R	B	SRF1RB	ALASH	mg/kg(d)	6	20	20		43 300		1 490	3,4	1 280	3,0
SRF1R	B	SRF1RB	CAASH	mg/kg(d)	7	23	8		431 000		17 400	4	4 360	1,0
SRF1R	B	SRF1RB	CAOASH	mg/kg(d)	7	23	8		602 000		29 700	4,9	4 180	0,7
SRF1R	B	SRF1RB	DM	%	7	16	0		97,1		0,663	0,7	0,101	0,1
SRF1R	B	SRF1RB	FE2O3ASH	mg/kg(d)	7	24	4		12 900		1 860	14,4	970	7,5
SRF1R	B	SRF1RB	FEASH	mg/kg(d)	7	24	4		9 040		1 280	14,1	677	7,5
SRF1R	B	SRF1RB	K2OASH	mg/kg(d)	5	17	32		3 630		539	14,9	287	7,9
SRF1R	B	SRF1RB	KASH	mg/kg(d)	5	17	32		3 010		444	14,7	239	7,9
SRF1R	B	SRF1RB	MGASH	mg/kg(d)	7	25	0		11 900		948	8	147	1,2

Table B.2 (continued)

Sample	Method	Sample code	Parameter	Unit	<i>l</i>	<i>n</i>	<i>o</i> %	Mean (ref)	Mean	Recovery rate %	<i>s_R</i>	<i>C_{V,R}</i> %	<i>s_r</i>	<i>C_{V,r}</i> %
SRF1R	B	SRF1RB	MGOASH	mg/kg(d)	7	25	0		19 800		1 730	8,8	200	1,0
SRF1R	B	SRF1RB	NA2OASH	mg/kg(d)	7	25	0		4 460		692	15,5	316	7,1
SRF1R	B	SRF1RB	NAASH	mg/kg(d)	7	25	0		3 260		482	14,8	235	7,2
SRF1R	B	SRF1RB	R-INDEX4	%(d)	6	19	17		21,5		0,877	4,1	0,256	1,2
SRF1R	B	SRF1RB	R-INDEX9	%(d)	6	19	17		22,7		0,903	4,0	0,271	1,2
SRF1R	B	SRF1RB	SASH	mg/kg(d)	5	17	19		4 090		846	20,7	140	3,4
SRF1R	B	SRF1RB	SIASH	mg/kg(d)	6	21	16		81 800		3 870	4,7	3 260	4,0
SRF1R	B	SRF1RB	SIO2ASH	mg/kg(d)	6	21	16		176 000		9 440	5,4	6 850	3,9
SRF1R	B	SRF1RB	SO3ASH	mg/kg(d)	5	17	19		10 200		2 110	20,6	350	3,4
SRF1R	B	SRF1RB	TI02ASH	mg/kg(d)	6	21	16		5 790		342	5,9	178	3,1
SRF1R	B	SRF1RB	TIASH	mg/kg(d)	6	21	16		3 490		226	6,5	113	3,2

Table B.3 — Performance data for sample SRF1R method C (SRF1RC)

Sample	Method	Sample code	Parameter	Unit	<i>l</i>	<i>n</i>	<i>o</i> %	Mean (ref)	Mean	Recovery rate %	<i>s_R</i>	<i>C_{V,R}</i> %	<i>s_r</i>	<i>C_{V,r}</i> %
SRF1R	C	SRF1RC	A_DB	%(d)	9	23	12		24,4		0,593	2,4	0,448	1,8
SRF1R	C	SRF1RC	AL2O3ASH	mg/kg(d)	7	21	30		80 200		5 200	6,5	1 410	1,8
SRF1R	C	SRF1RC	ALASH	mg/kg(d)	7	21	30		42 400		2 750	6,5	743	1,7
SRF1R	C	SRF1RC	CAASH	mg/kg(d)	8	22	27		450 000		26 500	5,9	8 360	1,9
SRF1R	C	SRF1RC	CAOASH	mg/kg(d)	8	22	27		629 000		37 100	5,9	11 700	1,9
SRF1R	C	SRF1RC	DM	%	10	25	0		96,7		1,01	1,0	0,259	0,3
SRF1R	C	SRF1RC	FE2O3ASH	mg/kg(d)	7	21	30		12 900		2 390	18,5	657	5,1
SRF1R	C	SRF1RC	FEASH	mg/kg(d)	7	21	30		9 050		1 670	18,5	455	5,0
SRF1R	C	SRF1RC	K2OASH	mg/kg(d)	8	22	27		3 290		981	29,8	87,2	2,7
SRF1R	C	SRF1RC	KASH	mg/kg(d)	8	22	27		2 730		815	29,8	79,3	2,9
SRF1R	C	SRF1RC	MGASH	mg/kg(d)	6	15	50		10 900		785	7,2	121	1,1
SRF1R	C	SRF1RC	MGOASH	mg/kg(d)	6	16	47		18 200		1 300	7,2	215	1,2
SRF1R	C	SRF1RC	NA2OASH	mg/kg(d)	8	22	27		3 070		1 500	49,0	263	8,6
SRF1R	C	SRF1RC	NAASH	mg/kg(d)	8	22	27		2 270		1 120	49,2	198	8,7
SRF1R	C	SRF1RC	R-INDEX4	%(d)	8	22	27		21,4		1,75	8,2	0,346	1,6
SRF1R	C	SRF1RC	R-INDEX9	%(d)	8	22	27		22,4		1,79	8,0	0,364	1,6
SRF1R	C	SRF1RC	SASH	mg/kg(d)	7	19	27		4 250		1 370	32,3	85,9	2,0
SRF1R	C	SRF1RC	SIASH	mg/kg(d)	8	21	30		77 600		9 000	11,6	1 600	2,1
SRF1R	C	SRF1RC	SIO2ASH	mg/kg(d)	8	22	27		166 000		19 000	11,5	3 300	2,0
SRF1R	C	SRF1RC	SO3ASH	mg/kg(d)	7	19	27		10 600		3 430	32,3	214	2,0
SRF1R	C	SRF1RC	TI02ASH	mg/kg(d)	8	22	27		5 770		886	15,4	187	3,2
SRF1R	C	SRF1RC	TIASH	mg/kg(d)	8	22	27		3 460		527	15,3	109	3,2

Table B.4 — Performance data for sample SRF1R direct method for sulfur (SRF1RS)

Sample	Method	Sample code	Parameter	Unit	<i>l</i>	<i>n</i>	<i>o</i> %	Mean (ref)	Mean	Recovery rate %	<i>s_R</i>	<i>C_{V,R}</i> %	<i>s_r</i>	<i>C_{V,r}</i> %
SRF1R	S	SRF1RS	A_DB	%(d)	6	16	20		24,4		0,702	2,9	0,167	0,7
SRF1R	S	SRF1RS	DM	%	8	19	0		96,8		0,564	0,6	0,114	0,1
SRF1R	S	SRF1RS	SASH	mg/kg(d)	2	5	81		4 340		186	4,3	179	4,1
SRF1R	S	SRF1RS	SO3ASH	mg/kg(d)	2	5	81		10 900		501	4,6	448	4,1

NOTE Direct method for sulfur S, see ISO 21663^[2] or ASTM D5016-16.^[3]

Table B.5 — Performance data for ash sample SRF4RA1 method A (SRF4RA1A)

Sample	Method	Sample code	Parameter	Unit	<i>l</i>	<i>n</i>	<i>o</i> %	Mean (ref)	Mean	Recovery rate %	<i>s_R</i>	<i>C_{V,R}</i> %	<i>s_r</i>	<i>C_{V,r}</i> %
SRF4RA1	A	SR-F4RA1A	AL2O3ASH	mg/kg(<i>d</i>)	11	41	13		133 000		19 700	14,8	16 900	12,7
SRF4RA1	A	SR-F4RA1A	ALASH	mg/kg(<i>d</i>)	11	41	13	74 711	70 500	94	10 400	14,8	8 940	12,7
SRF4RA1	A	SR-F4RA1A	CAASH	mg/kg(<i>d</i>)	11	41	13	229 553	227 000	99	22 200	9,8	13 600	6,0
SRF4RA1	A	SR-F4RA1A	CAOASH	mg/kg(<i>d</i>)	11	41	13		315 000		32 200	10,2	18 900	6,0
SRF4RA1	A	SR-F4RA1A	DM_ASH	%	9	17	0		98,8		2,09	2,1	0,139	0,1
SRF4RA1	A	SR-F4RA1A	FE2O3ASH	mg/kg(<i>d</i>)	10	38	19		57 300		4 240	7,4	2 220	3,9
SRF4RA1	A	SR-F4RA1A	FEASH	mg/kg(<i>d</i>)	10	38	19	42 047	40 100	95	2 960	7,4	1 550	3,9
SRF4RA1	A	SR-F4RA1A	K2OASH	mg/kg(<i>d</i>)	10	35	26		3 290		541	16,5	124	3,8
SRF4RA1	A	SR-F4RA1A	KASH	mg/kg(<i>d</i>)	10	35	26	3 162	2 730	86	449	16,5	103	3,8
SRF4RA1	A	SR-F4RA1A	MGASH	mg/kg(<i>d</i>)	12	43	9	33 453	31 800	95	3 430	10,8	686	2,2
SRF4RA1	A	SR-F4RA1A	MGOASH	mg/kg(<i>d</i>)	12	43	9		52 800		5 650	10,7	1 140	2,2
SRF4RA1	A	SR-F4RA1A	NA2OASH	mg/kg(<i>d</i>)	10	35	19		8 330		845	10,1	251	3,0
SRF4RA1	A	SR-F4RA1A	NAASH	mg/kg(<i>d</i>)	10	35	19	6 408	6 180	96	627	10,1	186	3,0
SRF4RA1	A	SR-F4RA1A	SASH	mg/kg(<i>d</i>)	10	36	3	23 308	21 600	93	2 640	12,2	701	3,2
SRF4RA1	A	SR-F4RA1A	SIASH	mg/kg(<i>d</i>)	10	35	19	139 719	139 000	99	18 200	13,1	7 760	5,6
SRF4RA1	A	SR-F4RA1A	SiO2ASH	mg/kg(<i>d</i>)	10	35	19		298 000		38 900	13,1	16 600	5,6
SRF4RA1	A	SR-F4RA1A	SO3ASH	mg/kg(<i>d</i>)	10	36	3		54 000		6 600	12,2	1 750	3,2
SRF4RA1	A	SR-F4RA1A	TiO2ASH	mg/kg(<i>d</i>)	11	42	11		36 200		1 790	4,9	960	2,7
SRF4RA1	A	SR-F4RA1A	TIASH	mg/kg(<i>d</i>)	11	42	11	22 176	21 700	98	1 070	4,9	575	2,7

Table B.6 — Performance data for ash sample SRF4RA1 method B (SRF4RA1B)

Sample	Method	Sample code	Parameter	Unit	<i>l</i>	<i>n</i>	<i>o</i> %	Mean (ref)	Mean	Recovery rate %	<i>s_R</i>	<i>C_{V,R}</i> %	<i>s_r</i>	<i>C_{V,r}</i> %
SRF4RA1	B	SRF4R-A1B	AL2O3ASH	mg/kg(<i>d</i>)	5	17	19		120 000		14 600	12,2	14 600	12,2
SRF4RA1	B	SRF4R-A1B	ALASH	mg/kg(<i>d</i>)	5	17	19		63 600		7 750	12,2	7 750	12,2
SRF4RA1	B	SRF4R-A1B	CAASH	mg/kg(<i>d</i>)	6	21	0		202 000		12 200	6,1	4 770	2,4
SRF4RA1	B	SRF4R-A1B	CAOASH	mg/kg(<i>d</i>)	6	21	0		280 000		17 400	6,2	6 520	2,3
SRF4RA1	B	SRF4R-A1B	DM_ASH	%	4	9	18		99,8		0,079 6	0,1	0,037 9	0,04
SRF4RA1	B	SRF4R-A1B	FE2O3ASH	mg/kg(<i>d</i>)	6	20	5		55 100		2 480	4,5	1 420	2,6
SRF4RA1	B	SRF4R-A1B	FEASH	mg/kg(<i>d</i>)	6	20	5		38 500		1 700	4,4	899	2,3