This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.

Designation: E2927 – 16

Standard Test Method for Determination of Trace Elements in Soda-Lime Glass Samples Using Laser Ablation Inductively Coupled Plasma Mass Spectrometry for Forensic Comparisons[1]

This standard is issued under the fixed designation E2927; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

INTRODUCTION

One objective of a forensic glass examination is to compare glass samples to determine if they may be discriminated using their physical, optical or chemical properties (for example, color, refractive index (RI), density, elemental composition). If the samples are distinguishable in any of these observed and measured properties, it may be concluded that they did not originate from the same source of broken glass. If the samples are indistinguishable in all of these observed and measured properties, the possibility that they originated from the same source of glass may not be eliminated. The use of an elemental analysis method such as laser ablation inductively coupled plasma mass spectrometry yields high discrimination among sources of glass.

1. Scope

1.1 This test method covers a procedure for the quantitative elemental analysis of the following seventeen elements: lithium (Li), magnesium (Mg), aluminum (Al), potassium (K), calcium (Ca), iron (Fe), titanium (Ti), manganese (Mn), rubidium (Rb), strontium (Sr), zirconium (Zr), barium (Ba), lanthanum (La), cerium (Ce), neodymium (Nd), hafnium (Hf) and lead (Pb) through the use of Laser Ablation Inductively Coupled Plasma Mass Spectrometry (LA-ICP-MS) for the forensic comparison of glass fragments. The potential of these elements to provide the best discrimination among different sources of soda-lime glasses has been published elsewhere (**1-5**).[2] Silicon (Si) is also monitored for use as a normalization standard. Additional elements may be added as needed, for example, tin (Sn) can be used to monitor the orientation of float glass fragments.

1.2 The method only consumes approximately 0.4 to 2 μg of glass per replicate and is suitable for the analysis of full thickness samples as well as irregularly shaped fragments as small as 0.1 mm by 0.4 mm in dimension. The concentrations of the elements listed above range from the low parts per million ($\mu g g^{-1}$) to percent (%) levels in soda-lime-silicate glass, the most common type encountered in forensic cases. This standard method may be applied for the quantitative analysis of other glass types; however, some modifications in the reference standard glasses and the element menu may be required.

1.3 This standard does not replace knowledge, skill, ability, experience, education or training and should be used in conjunction with professional judgment.

1.4 The values stated in SI units are to be regarded as standard. No other units of measurement are included in this standard.

1.5 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

1.6 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

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[1] This test method is under the jurisdiction of ASTM Committee E30 on Forensic Sciences and is the direct responsibility of Subcommittee E30.01 on Criminalistics.

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[2] The boldface numbers in parentheses refer to a list of references at the end of this standard.

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2. Referenced Documents

2.1 *ASTM Standards:*[3]

E2330 Test Method for Determination of Concentrations of Elements in Glass Samples Using Inductively Coupled Plasma Mass Spectrometry (ICP-MS) for Forensic Comparisons

E177 Practice for Use of the Terms Precision and Bias in ASTM Test Methods

C162 Terminology of Glass and Glass Products

3. Terminology

3.1 *Definitions:*

3.1.1 *calibration standard, n*—used to determine the quantitative analysis for the analyte elements of interest in the glass matrix. The calibration standard(s) shall have a known elemental composition including a known uncertainty for the reported analytes.

3.1.2 *glass, n*—an inorganic product of fusion that has been cooled to a rigid condition without crystallization. **C162**

3.1.3 *normalization standard, n*—an element that is present in the glass matrix at elevated and relatively homogeneous concentration that may be used to normalize the laser ablation signal to compensate for any variation on the ablated mass or instrumental drift.

4. Summary of Test Method

4.1 The glass fragments usually do not require sample preparation prior to the LA-ICP-MS analysis. However, they may be washed with solvents or pre-ablated if necessary.

4.2 The glass fragment is placed inside an ablation chamber and a laser beam is focused on the surface of the sample. When the ablation is started, the interaction between the pulsed laser and the sample surface produces a cloud of very small particles, which are transported from the ablation cell by a carrier gas into the ICP-MS for analysis.

4.3 An ICP-MS is used to quantify the elements of interest.

4.4 Quantitative analysis is accomplished using well-characterized glass standards whose major elemental composition is similar to the material to be analyzed.

4.5 A comparison between the reported elemental compositions of the known and recovered glass fragments may result in a decision on whether the samples are distinguishable by elemental composition or indistinguishable by elemental composition.

5. Significance and Use

5.1 This test method is useful for the determination of elemental concentrations in the microgram per gram ($\mu g g^{-1}$) to percent (%) levels in soda-lime glass samples. A standard test method may aid in the interchange of data between laboratories and in the creation and use of glass databases.

5.2 The determination of elemental concentrations in glass provides high discriminating value in the forensic comparison of glass fragments.

5.3 This test method produces minimal destruction of the sample. Microscopic craters of 50 to 100 µm in diameter by 80 to 150-µm deep are left in the glass fragment after analysis. The mass removed per replicate is approximately 0.4 to 3.1 µg.

5.4 Appropriate sampling techniques shall be used to account for natural heterogeneity of the materials at a microscopic scale.

5.5 The precision, accuracy, and limits of detection of the method (for each element measured) shall be established in each laboratory that employs the method. The measurement uncertainty of any concentration value used for a comparison shall be recorded with the concentration.

5.6 Acid digestion of glass followed by either Inductively Coupled Plasma-Optical Emission Spectrometry (ICP-OES) or Inductively Coupled Plasma-Mass Spectrometry (ICP-MS) may also be used for trace elemental analysis of glass, and offer similar detection levels and the ability for quantitative analysis. However, these methods are destructive, and require larger sample sizes and much longer sample preparation times (Test Method E2330).

5.7 Micro X-Ray Fluorescence (µ-XRF) uses comparable sample sizes to those used for LA-ICP-MS with the advantage of being non-destructive of the sample. Some of the drawbacks of µ-XRF are poorer sensitivity and precision, and longer analysis time.

5.8 Scanning Electron Microscopy with EDS (SEM-EDS) is also available for elemental analysis, but it is of limited use for forensic glass source discrimination due to poor detection limits for higher atomic number elements present in glass at trace concentration levels. However, distinguishing between sources having similar RIs and densities is possible.

6. Apparatus

6.1 *LA-ICP-MS*—A Laser Ablation system coupled to an ICP-MS instrument is employed. Since there are several manufacturers for both laser ablation units and ICP-MS instruments, the instrument maker, model, configuration, and major operational parameters (that is, laser wavelength for the laser and mass selective detector type for the ICP-MS) of both instruments shall be noted within the analysis results. The most common laser wavelengths used for glass analysis are 266 nm, 213 nm, and 193 nm. Either quadrupole or magnetic sector ICP-MS instruments are suitable for this test method.

6.2 Prior to the analysis on the day it is used, the ICP-MS shall be tuned according to the manufacturer's recommendations covering the mass range of the elements to be measured. The instrument shall be adjusted for maximum sensitivity, best precision, and to minimize oxides and doubly charged ion interferences. The use of a glass reference material, such as NIST 612,[4] is recommended during the tuning and performance check. Detector cross calibrations (pulse/analog) shall

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[3] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[4] Available from National Institute of Standards and Technology (NIST), 100 Bureau Dr., Stop 1070, Gaithersburg, MD 20899-1070, http://www.nist.gov.

be performed before any measurements when two detector modes are used in the analysis.

6.3 In order to prepare for data acquisition, the signals of the following isotopes are monitored in the ICP-MS; lithium (^{7}Li), magnesium (^{24} or ^{25}Mg), aluminum (^{27}Al), silicon (^{29}Si), potassium (^{39}K), calcium (^{42}Ca), iron (^{57}Fe), titanium (^{49}Ti), manganese (^{55}Mn), rubidium (^{85}Rb), strontium (^{88}Sr), zirconium (^{90}Zr), tin (^{118}Sn), barium (^{137}Ba), lanthanum (^{139}La), cerium (^{140}Ce), neodymium (^{146}Nd), hafnium (^{180}Hf) and lead (^{208}Pb). This procedure may be applicable to other elements and other isotopes (for example, $^{206,\ 207}$Pb); however, those elements listed above are considered to provide the most discrimination power for soda-lime glass comparisons. Alternatively, other isotopes such as ^{56}Fe may be monitored using ICP-MS with advanced technology to remove interferences (for example, sector field ICP-MS or reaction cells).

6.4 Either argon or helium may be used as a carrier gas to transport the particles from the ablation cell to the plasma. The use of helium carrier gas has been reported to result in fewer fractionation effects than the use of argon as a carrier (**6**).

7. Hazards

7.1 Commercial laser ablation units are enclosed type I lasers. However, laser systems typically used for analysis of glass generate high energy radiation that may pose serious risks to eye safety if exposed to the eye. Interlocks shall not be bypassed or disconnected.

7.2 The argon plasma shall not be observed directly without protective eyewear. Potentially hazardous UV light may be emitted.

7.3 ICP-MS instruments generate high amounts of radiofrequency energy in their RF power supply and torch boxes that is potentially hazardous if allowed to escape. Safety devices and safety interlocks shall not be bypassed or disconnected.

8. Calibration and Standardization

8.1 A calibration curve using multiple glass standards or using a single glass standard may be used for quantitation for LA-ICP-MS analysis of glass. Any calibration standard shall be matrix-matched to the sample and well-characterized. The calibration standard(s) shall be traceable to an accepted standard. For glass analysis there are several standards that are available such as the NIST Standard Reference Materials (that is, NIST 610, NIST 612, NIST 614) and the float glass standard glasses (FGS1, FGS2) evaluated by the European group NITECRIME (**5**) and distributed by the Bundeskriminalamt, Germany.[5] A normalization standard, preferably silicon (^{29}Si), shall be used to normalize the signal. The use of a normalization standard is needed to adjust for differences in ablation yield between the ablated materials. Since silicon is present as a major component in all soda-lime glass (~70 to 72 % as SiO_2) (**3, 7**), a low abundance isotope (^{29}Si) is commonly used as the normalization standard for this method. If this method is used for the analysis of other glass types, the concentration of the normalization standard shall be determined prior to quantitative analysis.

8.2 In addition to the calibration standard, at least one additional glass standard reference material shall should be measured with each sample set as a quality control check for the accuracy and precision of the method. The quality control specifications shall be set by each laboratory.

8.3 As a minimum, calibration standards are required at the beginning and the end of the analytical sequence in order to adjust for instrument drift over time. Acceptance criteria for the calibration shall be defined by each laboratory and shall include the use of calibration verification standards.

9. Procedure

9.1 If necessary, samples may be cleaned to remove any surface contamination by washing or pre-ablation, or both, prior to analysis. Cleaning may include washing samples with soap and water, with or without ultrasonication, and rinsing in deionized water, followed by rinsing in acetone, methanol, or ethanol, and drying. Soaking in various concentrations of nitric acid for 30 minutes or longer, rinsing with deionized water and ethanol, and drying prior to analysis removes most surface contamination without affecting the measured concentrations of elements inherent in the glass. However, the use of nitric acid may remove some surface coatings that may be present.

9.2 Multiple samples and standards may be placed together in the ablation cell as long as their positions are documented.

9.3 The samples or standards, or both, shall be secured in the ablation cell using double-sided tape or other adhesive. Orient the sample to avoid an original surface of the glass. The known and questioned samples shall be treated equally. The following steps shall be followed:

9.3.1 Purge the ablation cell with the carrier gas between samples to avoid any contamination.

9.3.2 If pre-ablation cleaning is performed it may be done at this point.

9.3.3 Focus the laser beam at the surface of the sample. Single spot (or depth profile) ablation modes are recommended at a spot size of ~50 to 100 µm and a repetition rate of 10 Hz. Program the laser parameters.

9.3.4 Initiate the acquisition of the analytical signals using the ICP-MS software. Each data acquisition shall be comprised of a transient signal of intensity versus time for each element; each transient shall include 20–30 seconds of background (gas blank) measurement, followed by 50–60 seconds of ablation of the sample, followed by 10–30 seconds of post-ablation blank measurement.

9.4 Conduct replicate ablations at different locations within the fragment(s). Locations shall be spaced sufficiently to avoid possible debris from other ablation halos. Collect replicate measurements to ensure that the questioned glass fragments and known glass source(s) are adequately characterized. Analyze a minimum of three replicates on each questioned sample examined and nine replicates on known glass sources.

NOTE 1—It is recommended that the entire sequence be completed in a

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[5] Available from Bundeskriminalamt, Section KI 35, 65173 Wiesbaden, Germany, http://www.bka.de.

single session (a single day). As an example, when a known sample with 3 fragments is compared to a single recovered fragment, the analytical sequence may be as follows:

(*1*)	Calibration standard	(1st, 2nd, and 3rd spot)
(*2*)	"Known" fragment #1	(1st, 2nd, and 3rd spot)
(*3*)	"Recovered" fragment	(1st, 2nd, and 3rd spot)
(*4*)	Calibration verification standard	(1st, 2nd, and 3rd spot)
(*5*)	"Known" fragment #2	(1st, 2nd, and 3rd spot)
(*6*)	"Known" fragment #3	(1st, 2nd, and 3rd spot)
(*7*)	Calibration standard	(4th, 5th, and 6th spot)

NOTE 2—A symmetrical arrangement of the analytical sequence of standards and samples is advantageous in minimizing the effects that may result from instrumental drift.

9.5 Once the acquisition is completed, use the software of choice to integrate the transient signals and determine the element concentrations of the samples. Some data reduction software allows real time data reduction so the analytical data may be immediately checked after each ablation.

9.6 For each isotope, the transient signal shall be integrated, corrected for the gas blank and normalized to the ^{29}Si internal standard signal. The normalized signals shall be converted to element concentration units using the calibration. The data reduction software may be selected by each laboratory. Because of particle size effects that may lead to undesired fractionation, it is recommended that the first 15 seconds or more of data collected during ablation not be integrated. See Fig. 1 for illustration of transient signal integration recommendation.

10. Limits of detection (LOD) and Limit of Quantitation (LOQ)

10.1 Limits of detection and limits of quantitation were determined by laboratory analysis procedures prior to publication of this test method. Limits of detection (LOD) were determined for each element by measuring procedure blanks on two non-consecutive days using a quadrupole ICP-MS and a Nd-YAG 213-nm laser. Each day, the mean and standard deviation of replicate measurements were calculated. LODs were computed as 3 times the standard deviation. LOQs were computed as 10 times the standard deviation. Normalized intensities were converted to concentrations using the calibration data for each element for that day. Values reported in Appendix X1 are two-day averages.

10.2 Table X1.1 gives the LODs, LOQs, and concentrations measured for sets of previously analyzed soda-lime glass samples. All values are expressed as µgg^{-1}.

11. Calculation and Interpretation of Results

11.1 The procedure below shall be followed to conduct a forensic glass comparison using the recommended match criteria is as follows (**8-11**):

11.1.1 For the Known source fragments, using a minimum of 9 measurements (from at least 3 fragments, if possible), calculate the mean for each element.

11.1.2 Calculate the standard deviation for each element. This is the Measured SD.

11.1.3 Calculate a value equal to at least 3% of the mean for each element. This is the Minimum SD.

11.1.4 Calculate a match interval for each element with a lower limit equal to the mean minus 4 times the SD (Measured or Minimum, whichever is greater) and an upper limit equal to the mean plus 4 times the SD (Measured or Minimum, whichever is greater).

11.1.5 For each Recovered fragment, using as many measurements as practical, calculate the mean concentration for each element.

11.1.6 For each element, compare the mean concentration in the Recovered fragment to the match interval for the corresponding element from the Known fragments.

11.1.7 If the mean concentration of one (or more) element(s) in the Recovered fragment falls outside the match interval for the corresponding element in the Known fragments, the element(s) does not "match" and the glass samples are considered distinguishable.

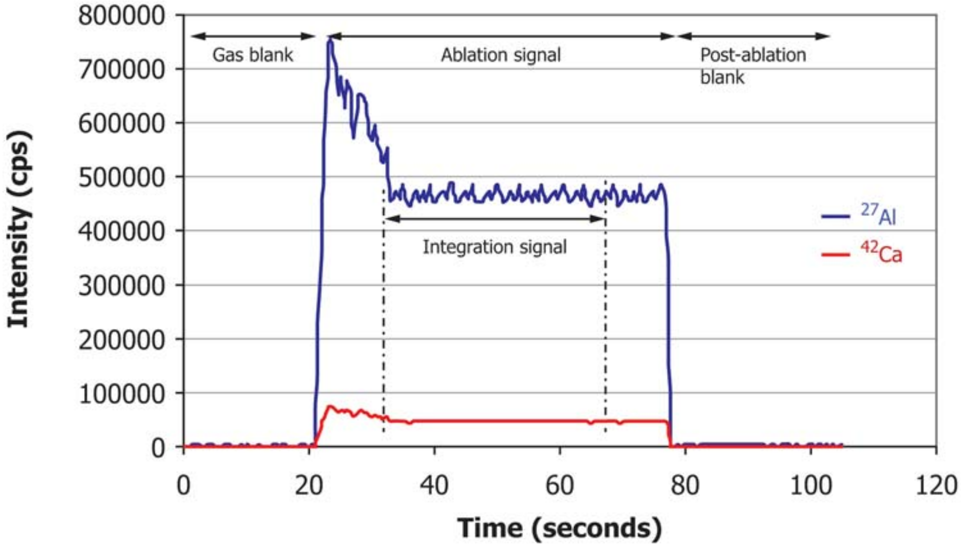

FIG. 1 Typical Ablation Signal for Glass

12. Precision and Bias

12.1 An interlaboratory study was conducted in 2009 by the Elemental Analysis Working Group (EAWG). All analyses were conducted by LA-ICP-MS using either NIST 612 or the FGS calibration standards. Each of seven laboratories tested three standard reference glasses using 7 replicate sample measurements of NIST 1831, FGS1 and FGS2. The standard NIST 1831 is a soda-lime sheet glass manufactured by NIST. The standards FGS1 and FGS2 are soda-lime glasses manufactured by SCHOTT AG[6] and distributed by the Bundeskriminalamt (**5**).

12.2 The bias and precision results for each of the glasses are tabulated in Appendix X2. The terms repeatability and reproducibility are used as specified in Practice E177. As suggested by this practice, the precision indices (95 % limits) were calculated by multiplying the respective standard deviation percentages by a factor of 2.8.

13. Keywords

13.1 forensic science; glass comparisons; glass measurement; trace elemental analysis; laser ablation; inductively coupled plasma mass spectrometry; LA-ICP-MS

APPENDIXES

(Nonmandatory Information)

X1. LIMITS OF DETECTION AND LIMITS OF QUANTITATION

X1.1 See Table X1.1.

TABLE X1.1 Expected Limits of Detection (LOD) and Limits of Quantitation (LOQ) for the Elements Described in This LA-ICP-MS Method for a Quadrupole ICP-MS System

NOTE 1—All values reported in µgg^{-1}.

Element	Limit of Detection, LOC, µgg^{-1}	Limit of Quantitation, LOQ, µgg^{-1}	Range of Concentrations, µgg^{-1}
Li	0.75	2.5	0.8 – 7.0^{A}
Mg	0.52	1.7	6270 – 51100^{B}
Al	1.9	6.3	297 – 11900^{B}
K	2.2	7.3	45 – 6330^{B}
Ca	150	480	46100 – 69800^{A}
Fe	9.2	30	460 – 6060^{B}
Ti	3.2	11	40 – 2320^{B}
Mn	0.77	25	9.0 – 470^{B}
Rb	0.19	0.63	0.3 – 33^{B}
Sr	0.072	0.24	19 – 576^{B}
Zr	0.13	0.43	19 – 269^{B}
Sn	0.52	1.7	11 – 2180^{A}
Ba	0.30	0.99	3.0 – 384^{B}
La	0.050	0.17	1.0 – 19^{B}
Ce	0.028	0.092	2 – 1900^{B}
Nd	0.17	0.56	0.8 – 8.0^{A}
Hf	0.090	0.30	0.5 – 7.0^{B}
Pb	0.16	0.53	0.3 – 250^{B}

^{A} From actual measurement of a set of 127 soda-lime glass samples from vehicle and architectural windows.

^{B} From actual measurement of a set of 286 soda-lime glass samples from vehicle and architectural windows.

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[6] Available from SCHOTT North America, Inc., Corporate Office, 555 Taxter Road, Elmsford, NY 10523, http://www.us.schott.com.

X2. BIAS AND PRECISION

X2.1 See Table X2.1, Table X2.2, and Table X2.3.

TABLE X2.1 Bias and Precision Found in SRM NIST 1831, Obtained from Interlaboratory Study

Element	Reported Value, μgg^{-1}	Average,[D] μgg^{-1}	Bias, %	Repeatability-Within s_r (%)	Reproducibility-between s_R (%)	Repeatability Limit-Within s_r (%)	Reproducibility Limit-between s_R (%)
Li	5.00[A]	5.3	7.0	5.1	5.6	14	16
Mg	21200[B]	23900	13	1.1	10	3.0	28
Al	6380[B]	6400	0.3	1.1	9.3	3.1	26
K	2740[B]	2690	–1.8	2.3	7.2	6.5	20
Ca	5860[B]	58000	–1.0	2.6	3.9	7.3	11
Fe	608[B]	500	–18	2.7	22	7.6	62
Ti	114[B]	130	14	2.6	7.0	7.3	20
Mn	15.00[C]	13.1	–13	1.8	2.4	5.0	6.8
Rb	6.11[C]	6.0	–1.8	2.4	3.8	6.8	11
Sr	89.12[C]	85	–5.0	2.2	4.6	5.5	13
Zr	43.36[C]	36	–17	2.2	6.8	6.2	19
Ba	31.5[C]	30.0	–4.4	2.6	6.7	7.2	19
La	2.12[A]	2.2	4.2	2.6	6.7	7.3	19
Ce	4.54[C]	44	–3.1	2.6	3.8	7.3	11
Nd	1.69[A]	1.8	4.1	2.3	7.1	6.5	20
Hf	1.10[C]	0.96	–13	3.7	8.5	10	24
Pb	1.99[C]	1.8	–11	5.0	6.7	14	19

[A] Historical data from a single lab over one year period (n = 42 days over a period of a year).

[B] Certified by NIST.

[C] Reported in Test Method E2330, values obtained by acid digestion ICP-MS interlaboratory test.

[D] Average value obtained from seven participant laboratories using different manufacturer LA and ICP-MS instruments.

TABLE X2.2 Bias and Precision Found in FGS1, Obtained from Interlaboratory Study

Element	Reported Value,[A] μgg^{-1}	Average,[B] μgg^{-1}	Bias, %	Repeatability-Within s_r (%)	Reproducibility-between s_R (%)	Repeatability Limit-Within s_r (%)	Reproducibility Limit-between s_R (%)
Li	6.0	5.9	–1.7	4.5	8.2	13	23
Mg	23900	26700	12	1.6	8.4	4.5	24
Al	1500	1580	5.3	2.2	3.8	6.1	11
K	920	1020	10	4.1	5.3	11	15
Ca	60600	59200	–2.3	1	5.9	2.7	17
Fe	580	490	–16	1.6	20	4.5	55
Ti	69	80	17	4.5	9.1	13	25
Mn	43	44.2	2.7	0.8	2.2	2.2	6.2
Rb	8.6	7.52	–12.6	2.8	5.2	7.8	15
Sr	57	55.7	–2.3	2.3	5.8	6.3	16
Zr	49	46.1	–6	2.4	8.9	6.7	25
Ba	40	40	1	2.8	7.8	7.8	22
La	4.3	4.2	–2.3	4.2	6.7	12	19
Ce	5.2	4.96	–4.6	0.9	7.8	2.4	22
Nd	5.1	5.0	–2.4	3.8	7.7	10	22
Hf	3.2	2.92	–8.8	2.4	11	7.0	30
Pb	5.8	5.04	–13	1.6	2.7	5.0	8.0

[A] Consensus values reported in Ref **(5)** (n = 5 – 10).

[B] Average value obtained from seven participant laboratories using different manufacturer LA and ICP-MS instruments.

TABLE X2.3 Bias and Precision Found in FGS2, Obtained from Interlaboratory Study

Element	Reported Value,[A] μgg^{-1}	Average,[B] μgg^{-1}	Bias, %	Repeatability-Within s_r (%)	Reproducibility-between s_R (%)	Repeatability Limit-Within s_r (%)	Reproducibility Limit-between s_R (%)
Li	29	26	–10	1.7	4	4.7	11
Mg	23400	26000	11	1.1	9.2	3.0	26
Al	7400	7600	2.6	1.1	7.3	3.1	20
K	4600	4900	6.5	0.8	6.5	2.1	18
Ca	59300	59000	–0.5	1.3	6.8	3.7	19
Fe	2600	2400	–7.6	1.5	19	4.2	54
Ti	326	381	17	1.3	9.9	3.6	28
Mn	221	221	0.2	2.3	2.3	6.4	6.3
Rb	35	38	8.6	1.5	4.1	4.1	11
Sr	253	255	0.8	0.7	6.4	1.9	18
Zr	223	221	–0.9	1.8	9.7	5.0	29
Ba	199	200	0.5	1.3	8.9	3.6	25
La	18	19	5.6	1.5	8.2	4.2	23
Ce	23	24	4.3	3.5	6.4	9.8	18
Nd	25	25	1.7	4.1	8.6	11	24
Hf	15	14	–6.7	2.3	11	6.0	32
Pb	24	24	1.5	1.8	4.4	5.0	12

[A] Consensus values reported in Ref **(5)** (n = 5 – 10).

[B] Average value obtained from seven participant laboratories using different manufacturer LA and ICP-MS instruments.

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