

## **Application Note**

### XRF 5039

# Lubricating Oil Analysis by Benchtop WDXRF According to ASTM D6443-04

Application lubricating oil



#### Introduction

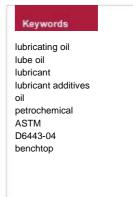
Lubricating oils are given specific functional properties by mixing additives with base oil. In order to assure consistent and desirable performance, it is very important to control the concentrations of the additives during the lubricant manufacturing process.

X-ray fluorescence (XRF) spectrometry has become increasingly popular for quantitative elemental analysis of base oils as well as additives and lubricant products thanks to its high precision and simple sample preparation. With liquids, sample preparation for XRF typically means pouring the sample into a plastic cup equipped with a transparent film. Unlike traditional techniques, such as Inductively-Coupled Plasma Optical Emission Spectroscopy (ICP-OES), XRF does not require chemical decomposition, digestion or serial dilution. ASTM D6443-04 specifies the use of the wavelength-dispersive (WD) XRF technique, because it offers sufficiently high precision, resolution and light-element sensitivity to meet the industry's needs.

Traditionally, WDXRF spectrometers have been large, floor-standing models with substantial installation requirements and high cost of component replacement. In its search for greater cost-efficiency, the lubricant industry is turning to tools that not only do the job, but are also easier and less expensive to acquire, install and maintain.

#### Instrument Benchtop wavelength dispersive X-ray fluorescence spectrometer Supermini200





This application note demonstrates the capability of low-cost, compact benchtop WDXRF spectrometer for quantitative elemental analysis of Ca, Cl, Cu, Mg, P, S and Zn in base oils, lubricating oils and additives.

#### Instrument

The Supermini200 is a benchtop sequential WDXRF spectrometer designed specifically to deliver excellent performance while eliminating typical installation requirements, such as cooling water, special power supply, large floor space, etc.

Featuring a unique air-cooled 200W X-ray tube, two detectors, programmable environment of vacuum or helium, and three analyzing crystals, the Supermini200 can analyze all relevant elements in just a few minutes with full spectral separation of all peaks and excellent sensitivity for light elements such as Mg, P and Cl.

The Windows-based software running the Supermini200 is shared with Rigaku's popular Primus family of higher-power WDXRF systems, which means that it has the same advanced algorithms, multiple language support and an intuitive user-friendly interface that have made Rigaku the world's leader in X-ray instrumentation and industrial applications.

#### Standards and sample preparation

Organometallic reference standard samples for lubricating oil provided by AccuStandard®, Inc. were used for calibration. Six grams of each sample was poured into a standard liquid cell (Chemplex® 1540) equipped with 4.0  $\mu m$  Prolene® (Chemplex® 416). The cups are disposable and inexpensive.

#### **Measurement conditions**

All elements were measured in a helium atmosphere, using standard crystals, with the X-ray tube operating at 50 kV and 4.0 mA. Peak and background intensities were counted for each element line, and the total counting time was less than nine minutes.

#### Calibration

In accordance with ASTM D6443-04, empirical matrix corrections were applied for all analytes, except Mg. The calibration results are listed in Table 1, with the corresponding calibration curves shown in Figure 1.

Table 1 Calibration results for all elements
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Element	Calibration Range (mass%)	Accuracy (mass%)	LLD (ppm)
Ca	0 - 0.50	0.0021	1.9
CI	0 - 0.15	0.0005	0.8
Cu	0 - 0.05	0.0006	1.1
Mg	0-0.20	0.0044	20
Р	0 - 0.15	0.0004	1.0
S	0 - 0.75	0.0032	0.9
Zn	0 - 0.15	0.0020	1.0

The accuracy of calibration was calculated by the following formula,

Accuracy = 
$$\sqrt{\frac{\sum_{i} (C_{i} - \hat{C}_{i})^{2}}{n-2}}$$

C<sub>i</sub> : calculated value of standard sample

- $\hat{C}_i$ : reference value of standard sample
- n : number of standard samples.

The lower limit of detection (LLD) was calculated as

$$LLD = 3 \cdot \frac{1}{m} \cdot \sigma_{\rm B} = \frac{3}{m} \cdot \sqrt{\frac{I_{\rm B}}{1000 \times t}}$$

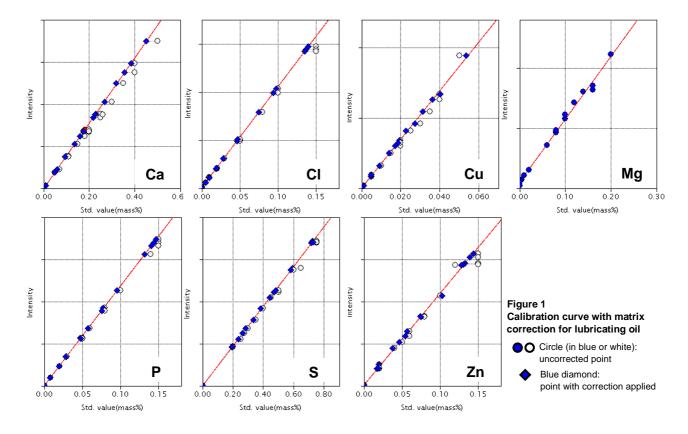
m : sensitivity of calibration (kcps/ppm)

- $\sigma_{\rm B}$ : standard deviation of blank intensity (kcps)
- $I_{\rm B}$  : blank intensity (kcps)
- t : counting time (s).

#### **Analysis results**

In order to assess the repeatability of the method, two aliquots of a representative sample were prepared and quantified with the calibration; this process was repeated twenty times.

The test data were compiled in Table 2, which shows the average and the difference of the results for each two-aliquot measurement. ASTM D6443-04 specifies that "the difference between successive test results obtained by the same operator with the same apparatus under constant operation conditions on identical test material...in the long run" must not exceed the values in Table 3, which shows the formula for the



#### Table 3 Repeatability as defined in ASTM D6443-04 (unit: mass%)

Element Concentration range Repeatability [r] Ca 0.001 - 0.200 0.006914 (X+0.0007)<sup>0.5</sup> CI 0.0356 (X+0.0086) 0.001 - 0.0300.002267 (X+0.0013)<sup>0.4</sup> Cu 0.001 - 0.030 0.01611 (X+0.0008)<sup>0.333</sup> Mg 0.003 - 0.200Р 0.001 - 0.200 0.02114 X<sup>0.7</sup> 0.02371 X<sup>0.9</sup> s 0.030 - 0.800 0.01225 X<sup>0.7</sup> Zn 0.001 - 0.200

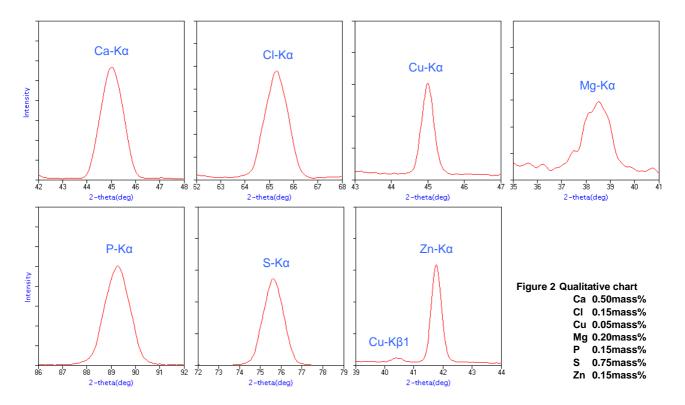
Note) X: concentration in mass%

#### maximum allowed repeatability (r) of each analyte. Please note that all units in Table 3 are in terms of mass%, including the standard's concentration X. The maximum actual difference between successive results in Table 2 is labeled "Max", while "r" represents

the maximum permissible difference as prescribed by the ASTM method (see Table 3). Since "Max" never exceeds "r", the repeatability of the Supermini200 easily satisfies the requirements of ASTM D6443-04.

Image         OC         Cu         Cu         Mage         Diff.         Arge         Diff.           1         0.0102         0.0001         0.0107         0.0000         0.0118         0.0002         0.0332         0.0020           2         0.0102         0.0001         0.0106         0.0002         0.0118         0.0001         0.0324         0.0004           3         0.1102         0.0000         0.0105         0.0002         0.0118         0.0001         0.0354         0.0003           4         0.0103         0.0001         0.0105         0.0002         0.0118         0.0002         0.0334         0.0033           7         0.0103         0.0001         0.0107         0.0001         0.0118         0.0004         0.0334         0.0033           0         0.0104         0.0017         0.0001         0.0118         0.0004         0.0334         0.0033           10         0.0102         0.0001         0.0119         0.0002         0.0334         0.0025           10         0.0102         0.0003         0.0166         0.0001         0.0119         0.0002         0.0334         0.0025           12         0.0102         0.00033	Table 2	2 Repeatability	test results						(unit: mass%)
1         0.0102         0.0001         0.0177         0.0000         0.0118         0.0022         0.0332         0.0202           2         0.0102         0.0001         0.0166         0.0001         0.0119         0.0001         0.0324         0.0002           4         0.0103         0.0001         0.0166         0.0000         0.0118         0.0002         0.0340         0.0027           5         0.0103         0.0000         0.0116         0.0002         0.0117         0.0002         0.0331         0.0003           6         0.0102         0.0001         0.0107         0.0000         0.0118         0.0002         0.0331         0.0044           8         0.0103         0.0001         0.0107         0.0000         0.0118         0.0001         0.0332         0.0033           9         0.0103         0.0001         0.0107         0.0001         0.0118         0.0001         0.0338         0.0055           11         0.0103         0.0001         0.0119         0.0002         0.0331         0.0002           12         0.0103         0.0001         0.0119         0.0002         0.0331         0.0002           13         0.0104         0.0				CI		Cu		Mg	
2         0.0102         0.0001         0.0106         0.0002         0.0118         0.0001         0.0324         0.0004           3         0.0102         0.0000         0.0116         0.0000         0.0118         0.0002         0.0328         0.0003           5         0.0103         0.0001         0.0166         0.0002         0.0118         0.0002         0.0351         0.0003           6         0.0102         0.0001         0.0165         0.0002         0.0118         0.00001         0.0333         0.0044           8         0.0104         0.0001         0.0107         0.0000         0.0118         0.0001         0.0333         0.0033           9         0.0103         0.0001         0.0107         0.0000         0.0118         0.0001         0.0333         0.0033           10         0.0102         0.0001         0.0117         0.0001         0.0133         0.0003         0.0166         0.0001         0.0118         0.0001         0.0333         0.00033         0.0003         0.0166         0.0001         0.0118         0.0001         0.0333         0.00033         0.00033         0.0006         0.0118         0.0001         0.0333         0.00033         0.0006		Avg.	Diff.	Avg.	Diff.	Avg.	Diff.	Avg.	Diff.
3         0.0102         0.0000         0.0106         0.0001         0.0119         0.0001         0.0021           4         0.0103         0.0001         0.0165         0.0002         0.0117         0.0000         0.0331         0.0005           6         0.0102         0.0000         0.0165         0.0002         0.0118         0.0000         0.0332         0.0003           7         0.0103         0.0001         0.0107         0.0000         0.0118         0.0004         0.0337         0.0044           8         0.0104         0.0001         0.0107         0.0000         0.0118         0.0001         0.0332         0.0033           9         0.0103         0.0001         0.0117         0.0001         0.0118         0.0001         0.0333         0.0065           10         0.0102         0.0001         0.0118         0.0001         0.0333         0.0003           12         0.0102         0.0003         0.0166         0.0001         0.0117         0.0002         0.0333         0.0003           13         0.0104         0.0002         0.0165         0.0001         0.0117         0.0000         0.0338         0.0003           14         0.	1	0.0102	0.0001	0.0107	0.0000	0.0118	0.0002	0.0332	0.0020
4         0.0103         0.0001         0.0106         0.0002         0.0118         0.0002         0.0311         0.0002         0.0311         0.0002         0.0331         0.0003           5         0.0103         0.0000         0.0105         0.0002         0.0118         0.00002         0.0331         0.0003           7         0.0103         0.0001         0.0107         0.0001         0.0118         0.0004         0.0334         0.0034           8         0.0104         0.0001         0.0107         0.0000         0.0118         0.0001         0.0338         0.0035           9         0.0103         0.0001         0.0107         0.0001         0.0119         0.0002         0.0338         0.0035           10         0.0102         0.0001         0.0119         0.0002         0.0333         0.0003           11         0.0102         0.0001         0.0119         0.0002         0.0333         0.0002           14         0.0102         0.0106         0.0001         0.0118         0.0001         0.0333         0.0002           15         0.0102         0.0002         0.0166         0.0001         0.0118         0.0001         0.0333         0.0005	2	0.0102	0.0001	0.0106	0.0002	0.0118	0.0001	0.0324	0.0004
5         0.0103         0.0001         0.0105         0.0002         0.0117         0.0000         0.0351         0.0005           6         0.0102         0.00000         0.0105         0.0002         0.0118         0.0001         0.0332         0.0044           8         0.0104         0.0001         0.0177         0.0001         0.01120         0.0001         0.0342         0.0043           9         0.0102         0.0001         0.0107         0.0001         0.0118         0.0001         0.0342         0.0043           10         0.0102         0.0001         0.0107         0.0001         0.0118         0.0001         0.0332         0.0043           11         0.0105         0.0001         0.0116         0.0001         0.0112         0.0000         0.0333         0.0032           12         0.0104         0.0002         0.0166         0.0001         0.0117         0.0000         0.0338         0.0022           13         0.0104         0.0002         0.0166         0.0001         0.0118         0.0001         0.0338         0.0002           14         0.0102         0.0002         0.0165         0.0001         0.0118         0.0001         0.0333	3	0.0102	0.0000	0.0106	0.0001	0.0119	0.0001	0.0326	0.0000
6         0.0102         0.0000         0.0105         0.0002         0.0118         0.0002         0.0332         0.0033           7         0.0103         0.0001         0.0107         0.0001         0.0117         0.0001         0.0331         0.0034           8         0.0104         0.0001         0.0107         0.0000         0.0118         0.0001         0.0342         0.0033           9         0.0103         0.0001         0.0107         0.0000         0.0118         0.0001         0.0332         0.0033           10         0.0102         0.0001         0.0106         0.0001         0.0118         0.0002         0.0331         0.0003           11         0.0105         0.0001         0.0118         0.0002         0.0331         0.0003           13         0.0104         0.0002         0.0106         0.0001         0.0118         0.0001         0.0333         0.0003           16         0.0102         0.0003         0.0106         0.0001         0.0118         0.0001         0.0338         0.0005           17         0.0104         0.0002         0.0105         0.0001         0.0118         0.0002         0.0338         0.0006	4	0.0103	0.0001	0.0106	0.0000	0.0118	0.0002	0.0340	0.0027
7         0.0103         0.0002         0.0107         0.0001         0.0120         0.0001         0.0337         0.0044           8         0.0104         0.0001         0.0107         0.0000         0.0118         0.0001         0.0342         0.0043           10         0.0102         0.0001         0.0107         0.00001         0.0118         0.0001         0.0338         0.0050           11         0.0105         0.0001         0.0106         0.0001         0.0119         0.0002         0.0331         0.0033           12         0.0105         0.0001         0.0166         0.0001         0.0118         0.0000         0.0338         0.0025           13         0.0102         0.0003         0.0166         0.0001         0.0118         0.0001         0.0338         0.0025           14         0.0102         0.0003         0.0166         0.0001         0.0118         0.0001         0.0338         0.0025           15         0.0102         0.0002         0.0166         0.0001         0.0118         0.0001         0.0338         0.0006           16         0.0104         0.0002         0.0165         0.0003         0.0118         0.0001         0.0338	5	0.0103	0.0001	0.0105	0.0002	0.0117	0.0000	0.0351	0.0005
8         0.0104         0.0001         0.0107         0.0000         0.0118         0.0004         0.0340         0.0039           9         0.0103         0.0001         0.0107         0.00001         0.0117         0.0001         0.0338         0.0050           11         0.0103         0.0001         0.0107         0.0001         0.0119         0.0002         0.0331         0.0035           12         0.0104         0.0002         0.0106         0.0001         0.0119         0.0002         0.0331         0.0032           13         0.0104         0.0002         0.0106         0.0001         0.0117         0.0002         0.0341         0.0032           14         0.0102         0.0003         0.0106         0.0001         0.0117         0.0000         0.0342         0.0016           16         0.0103         0.0000         0.0116         0.0001         0.0118         0.0001         0.0338         0.0023           18         0.0104         0.0002         0.0105         0.0003         0.0118         0.0001         0.0333         0.0003           10         0.0100         0.0003         0.0116         0.0011         0.0118         0.0002         0.0333	6	0.0102	0.0000	0.0105	0.0002	0.0118	0.0002	0.0332	0.0033
9         0.0103         0.0001         0.0107         0.0000         0.0117         0.0001         0.0342         0.0043           10         0.0102         0.0001         0.0107         0.0001         0.0118         0.0001         0.0338         0.0065           12         0.0105         0.0001         0.0106         0.0001         0.0119         0.0002         0.0331         0.0003           13         0.0104         0.0002         0.0106         0.0001         0.0119         0.0002         0.0341         0.0022           14         0.0102         0.0003         0.0106         0.0001         0.0117         0.0000         0.0342         0.0016           16         0.0102         0.0003         0.0105         0.0000         0.0118         0.0001         0.0342         0.0016           17         0.0104         0.0002         0.0105         0.0003         0.0118         0.0001         0.0338         0.0009           18         0.0104         0.0002         0.0104         0.0001         0.0338         0.0001           19         0.0102         0.0003         0.0118         0.0002         0.0338         0.0005           19         0.0100         <	7	0.0103	0.0002	0.0107	0.0001	0.0120	0.0001	0.0337	0.0044
10         0.0102         0.0001         0.0107         0.0001         0.0118         0.0001         0.0338         0.0050           11         0.0105         0.0001         0.0106         0.0001         0.0119         0.0002         0.0331         0.0005           12         0.0104         0.0002         0.0316         0.0001         0.0119         0.0002         0.0341         0.0035           13         0.0102         0.0003         0.0106         0.0001         0.0118         0.0001         0.0338         0.0025           15         0.0102         0.0003         0.0106         0.0001         0.0118         0.0001         0.0338         0.0026           16         0.0103         0.0105         0.0000         0.0340         0.0005         18         0.0011         0.0338         0.0009         19         0.0102         0.0102         0.0105         0.0003         0.0118         0.0001         0.0333         0.0009           19         0.0102         0.0102         0.0104         0.0001         0.0118         0.0002         0.0333         0.0003           10         0.0001         0.0476         0.0001         0.0118         0.0002         0.0339         0.0016 <td>8</td> <td>0.0104</td> <td>0.0001</td> <td>0.0107</td> <td>0.0000</td> <td>0.0118</td> <td>0.0004</td> <td>0.0340</td> <td>0.0039</td>	8	0.0104	0.0001	0.0107	0.0000	0.0118	0.0004	0.0340	0.0039
11         0.0103         0.0003         0.0106         0.0001         0.0119         0.0002         0.0331         0.0035           12         0.0104         0.0002         0.0106         0.0001         0.0120         0.0000         0.0353         0.0009           14         0.0102         0.0003         0.0106         0.0001         0.0118         0.0001         0.0334         0.0022           15         0.0102         0.0003         0.0106         0.0001         0.0117         0.0000         0.0334         0.0005           16         0.0103         0.0000         0.0165         0.0001         0.0118         0.0001         0.0333         0.0005           17         0.0104         0.0002         0.0105         0.0003         0.0118         0.0001         0.0333         0.0005           18         0.0102         0.0002         0.0105         0.0001         0.0118         0.0002         0.0338         0.0009           10         0.0100         0.0003         0.0118         0.0002         0.0338         0.0009           1         0.0003         0.0101         0.0116         0.0001         0.0016         0.0019           2         0.0100 <t< th=""><td>9</td><td>0.0103</td><td>0.0001</td><td>0.0107</td><td>0.0000</td><td>0.0117</td><td>0.0001</td><td>0.0342</td><td>0.0043</td></t<>	9	0.0103	0.0001	0.0107	0.0000	0.0117	0.0001	0.0342	0.0043
12         0.0105         0.0001         0.0106         0.0001         0.0112         0.0002         0.0333         0.0009           13         0.0104         0.0002         0.0106         0.0001         0.0119         0.0002         0.0341         0.0022           14         0.0102         0.0003         0.0106         0.0001         0.0118         0.0001         0.0338         0.0025           15         0.0104         0.0002         0.0105         0.0000         0.0118         0.0001         0.0338         0.0008           16         0.0104         0.0002         0.0106         0.0001         0.0118         0.0001         0.0333         0.0009           18         0.0104         0.0002         0.0104         0.0001         0.0118         0.0002         0.0333         0.0009           10         0.0102         0.0003         0.0105         0.0001         0.0118         0.0002         0.0333         0.0019           20         0.0100         0.0003         0.0001         0.0118         0.0002         0.0333         0.0019           20         0.0100         0.0001         0.0476         0.0001         0.0114         0.0001         0.0053	10	0.0102	0.0001	0.0107	0.0001	0.0118	0.0001	0.0338	0.0050
13         0.0104         0.0002         0.0106         0.0001         0.0119         0.0002         0.0341         0.0032           14         0.0102         0.0003         0.0106         0.0001         0.0118         0.0001         0.0338         0.0025           15         0.0102         0.0003         0.0106         0.0001         0.0117         0.0000         0.0338         0.0008           17         0.0104         0.0002         0.0106         0.0001         0.0118         0.0001         0.0333         0.0009           18         0.0104         0.0002         0.0105         0.0003         0.0118         0.0001         0.0333         0.0009           19         0.0102         0.0002         0.0105         0.0003         0.0118         0.0002         0.0333         0.0019           20         0.0100         0.0003         0.0116         0.0004         0.0053         0.0051           r         -         0.0007         0.0003         0.0113         0.0000         0.0016         0.0016         0.0016         0.0016         0.0016         0.0016         0.0011         0.0114         0.0001         0.0011         0.0114         0.0001         0.0011         0.0114 </th <td>11</td> <td>0.0103</td> <td>0.0003</td> <td>0.0106</td> <td>0.0001</td> <td>0.0119</td> <td>0.0002</td> <td>0.0331</td> <td>0.0035</td>	11	0.0103	0.0003	0.0106	0.0001	0.0119	0.0002	0.0331	0.0035
14         0.0102         0.0003         0.0106         0.0011         0.0118         0.0001         0.0338         0.0025           15         0.0102         0.0003         0.0106         0.0001         0.0117         0.0000         0.0342         0.016           16         0.0104         0.0002         0.0105         0.0000         0.0118         0.0001         0.0338         0.0008           17         0.0104         0.0002         0.0105         0.0003         0.0118         0.0001         0.0338         0.0009           18         0.0102         0.0002         0.0104         0.0001         0.0118         0.0002         0.0338         0.0009           19         0.0102         0.0003         0.0118         0.0002         0.0338         0.0019           20         0.0100         0.0003         0.0118         0.0002         0.0338         0.0050           r         0.0003         0.0014         0.0001         0.0118         0.0002         0.0338         0.0050           1         0.0000         0.0001         0.0476         0.0003         0.0113         0.0001         0.0051           2         0.0100         0.0001         0.0476	12	0.0105	0.0001	0.0106	0.0001	0.0120	0.0000	0.0353	0.0009
15         0.0102         0.0003         0.0106         0.0011         0.0117         0.0000         0.0342         0.0016           16         0.0103         0.0000         0.0118         0.0001         0.0338         0.0008           17         0.0104         0.0002         0.0106         0.0001         0.0118         0.0001         0.0334         0.0009           18         0.0104         0.0002         0.0106         0.0001         0.0118         0.0001         0.0333         0.0009           19         0.0102         0.0003         0.0105         0.0001         0.0118         0.0002         0.0338         0.0019           20         0.0100         0.0003         0.0118         0.0002         0.0338         0.0019           20         0.0003         0.0118         0.0002         0.0339         0.016           Max         0.0007         0.0007         0.0004         0.0053           1         0.0100         0.0001         0.0476         0.0003         0.0114         0.0001           2         0.0100         0.0001         0.0476         0.0005         0.0114         0.0001           3         0.0100         0.0003         0.0476 </th <td>13</td> <td>0.0104</td> <td>0.0002</td> <td>0.0106</td> <td>0.0001</td> <td>0.0119</td> <td>0.0002</td> <td>0.0341</td> <td>0.0032</td>	13	0.0104	0.0002	0.0106	0.0001	0.0119	0.0002	0.0341	0.0032
16         0.0103         0.0000         0.0105         0.0000         0.0118         0.0001         0.0338         0.0008           17         0.0104         0.0002         0.0105         0.0003         0.0118         0.0000         0.0338         0.0009           18         0.0104         0.0002         0.0105         0.0003         0.0118         0.0002         0.0338         0.0009           19         0.0100         0.0003         0.0105         0.0001         0.0118         0.0002         0.0339         0.0016           Max         0.0003         0.0105         0.0001         0.0118         0.0002         0.0339         0.0016           Max         0.0007         0.0007         0.0004         0.0050         0.0024         0.0053           r         0.0007         0.0007         0.0001         0.0113         0.0000         0.0051         0.0001         0.0151         0.0001         0.0151         0.0001         0.0151         0.0001         0.0161         0.0001         0.0161         0.0001         0.0161         0.0001         0.0161         0.0001         0.0161         0.0001         0.0161         0.0001         0.0161         0.0001         0.0114         0.00001	14	0.0102	0.0003	0.0106	0.0001	0.0118	0.0001	0.0338	0.0025
17         0.0104         0.0002         0.0106         0.0001         0.0118         0.0000         0.0340         0.0005           18         0.0104         0.0002         0.0105         0.0003         0.0118         0.0001         0.0333         0.0009           19         0.0100         0.0003         0.0118         0.0002         0.0338         0.0019           20         0.0100         0.0003         0.0118         0.0002         0.0339         0.0165           Max         0.0007         0.0007         0.0004         0.0050           r         0.0007         0.0007         0.0004         0.0050           r         -         0.0001         0.0474         0.0003         0.0114         0.0000           2         0.0100         0.0001         0.0476         0.0002         0.0114         0.0002         0.0114         0.0002           3         0.0100         0.0001         0.0476         0.0002         0.0114         0.0002         0.0114         0.0002           4         0.0100         0.0477         0.0003         0.0114         0.0001         0.477           5         0.0101         0.0477         0.00005         0.0114	15	0.0102	0.0003	0.0106	0.0001	0.0117	0.0000	0.0342	0.0016
18         0.0104         0.0002         0.0105         0.0003         0.0118         0.0001         0.0333         0.0009           19         0.0102         0.0003         0.0104         0.0011         0.0118         0.0002         0.0338         0.0019           20         0.0100         0.0003         0.0105         0.0001         0.0118         0.0002         0.0339         0.0016           Max         0.0003         0.0003         0.0003         0.0004         0.0050           r         0.0001         0.0007         0.0004         0.0053           r         0.0001         0.0474         0.0003         0.0114         0.0000         0.0051           1         0.0100         0.0001         0.0476         0.0001         0.0114         0.0001         0.0114         0.0002           3         0.0100         0.0001         0.0476         0.0002         0.0113         0.0001         0.0114         0.0002         0.0114         0.0002         0.0114         0.0003         0.0114         0.0001         0.0477         0.0002         0.0114         0.0001         0.0478         0.0001         0.0114         0.0001         0.0114         0.0001         0.0114         0.000	16	0.0103	0.0000	0.0105	0.0000	0.0118	0.0001	0.0338	0.0008
19         0.0102         0.0002         0.0104         0.0011         0.0118         0.0002         0.0338         0.0019           20         0.0100         0.0003         0.0105         0.0001         0.0118         0.0002         0.0339         0.0016           Max         0.0003         0.0003         0.0003         0.0004         0.0050           r         0.0001         0.474         0.0003         0.0113         0.0000           2         0.0100         0.0001         0.474         0.0002         0.0114         0.0001           3         0.0100         0.0001         0.477         0.0002         0.0114         0.0002         0.0011           4         0.0100         0.0001         0.477         0.0002         0.0114         0.0002         0.0011           4         0.0100         0.0001         0.477         0.0002         0.0114         0.0002         0.0114           6         0.0100         0.0003         0.477         0.0002         0.0114         0.0001         0.477           7         0.0098         0.0002         0.477         0.0002         0.1114         0.0001         0.114           9         0.1102         <	17	0.0104	0.0002	0.0106	0.0001	0.0118	0.0000	0.0340	0.0005
20         0.0100         0.0003         0.0105         0.0001         0.0118         0.0002         0.0339         0.0016           Max         0.0007         0.0007         0.0003         0.0004         0.0004         0.0050           r	18	0.0104	0.0002	0.0105	0.0003	0.0118	0.0001	0.0333	0.0009
Max         0.0003         0.0003         0.0004         0.0050           r         0.0007         S         Zn         0.0053           Avg.         Diff.         Avg.         Diff.         Avg.         Diff.         0.0001         0.0053           1         0.0100         0.0001         0.0474         0.0003         0.0113         0.0000         0.0114         0.0001           2         0.0100         0.0001         0.0476         0.0002         0.0114         0.0001         0.0011           3         0.0100         0.0001         0.0476         0.0002         0.0114         0.0002         0.0114         0.0001           4         0.0100         0.0001         0.0477         0.0002         0.0113         0.0001           5         0.0101         0.0017         0.0002         0.0113         0.0001         0.0011           6         0.0100         0.0003         0.0477         0.0002         0.0114         0.0003         0.0114           6         0.0100         0.0003         0.0477         0.0007         0.0113         0.0001           10         0.0102         0.0003         0.0477         0.0007         0.0113         0.	19	0.0102	0.0002	0.0104	0.0001	0.0118	0.0002	0.0338	0.0019
r         0.0007         0.0007         0.0004         0.0053           P         S         Zn         Control         Contro <thcontrol< th=""> <thcontrol< <="" th=""><td>20</td><td>0.0100</td><td>0.0003</td><td>0.0105</td><td>0.0001</td><td>0.0118</td><td>0.0002</td><td>0.0339</td><td>0.0016</td></thcontrol<></thcontrol<>	20	0.0100	0.0003	0.0105	0.0001	0.0118	0.0002	0.0339	0.0016
Avg.         Diff.         Avg.         Diff.         Avg.         Diff.           1         0.0100         0.0001         0.0474         0.0003         0.0113         0.0000           2         0.0100         0.0001         0.0476         0.0001         0.0114         0.0001           3         0.0100         0.0001         0.0476         0.0002         0.0115         0.0001           4         0.0100         0.0000         0.0476         0.0002         0.0113         0.0001           5         0.0101         0.0476         0.0002         0.0113         0.0001         0.0477           6         0.0100         0.0003         0.0477         0.0003         0.0114         0.0003           6         0.0100         0.0003         0.0476         0.0005         0.0114         0.0001           8         0.0100         0.0003         0.0476         0.0002         0.0113         0.0001           9         0.0102         0.0002         0.0477         0.0007         0.0113         0.0000           10         0.0102         0.0001         0.0479         0.0002         0.0113         0.0000           11         0.0101         0.04	Max		0.0003		0.0003		0.0004		0.0050
Avg.         Diff.         Avg.         Diff.         Avg.         Diff.           1         0.0100         0.0001         0.0474         0.0003         0.0113         0.0000           2         0.0100         0.0001         0.0476         0.0001         0.0114         0.0001           3         0.0100         0.0001         0.0477         0.0002         0.0115         0.0001           4         0.0100         0.0001         0.0474         0.0002         0.0113         0.0002           5         0.0101         0.0474         0.0002         0.0113         0.0001         0.0474           6         0.0100         0.0003         0.0477         0.0003         0.0114         0.0003           6         0.0100         0.0003         0.0474         0.0002         0.0113         0.0001           8         0.0100         0.0003         0.0476         0.0005         0.0114         0.0001           9         0.0102         0.0003         0.0477         0.0007         0.0113         0.0000           11         0.0102         0.0001         0.0478         0.0002         0.0114         0.0002           13         0.0101         0.04	r		0.0007		0.0007		0.0004		0.0053
1         0.0100         0.0001         0.0474         0.0003         0.0113         0.0000           2         0.0100         0.0001         0.0476         0.0001         0.0114         0.0001           3         0.0100         0.0001         0.0477         0.0002         0.0115         0.0001           4         0.0100         0.0000         0.0476         0.0005         0.0114         0.0002           5         0.0101         0.0477         0.0002         0.0113         0.0001           6         0.0100         0.0003         0.0477         0.0003         0.0114         0.0003           7         0.0098         0.0000         0.0478         0.0000         0.0114         0.0001           8         0.0100         0.0003         0.0477         0.0005         0.0114         0.0001           9         0.0102         0.0003         0.0479         0.0002         0.0113         0.0000           11         0.0101         0.0479         0.0002         0.0113         0.0000         0.0114           12         0.0102         0.0047         0.0001         0.0115         0.0000         0.0114           13         0.1011 <td< th=""><th></th><th></th><th>P</th><th></th><th>S</th><th></th><th>Zn</th><th></th><th></th></td<>			P		S		Zn		
2         0.0100         0.0001         0.0476         0.0001         0.0114         0.0001           3         0.0100         0.0001         0.0477         0.0002         0.0115         0.0001           4         0.0100         0.0000         0.0476         0.0005         0.0114         0.0002           5         0.0101         0.0001         0.0474         0.0002         0.0113         0.0001           6         0.0100         0.0003         0.0477         0.0003         0.0114         0.0003           7         0.0098         0.0000         0.0478         0.0000         0.0115         0.0001           8         0.0100         0.0002         0.0477         0.0007         0.0113         0.0000           9         0.0102         0.0002         0.0477         0.0007         0.0113         0.0000           10         0.0102         0.0003         0.0479         0.0002         0.0113         0.0000           11         0.0101         0.0478         0.0002         0.0114         0.0000         0.0012           12         0.0102         0.0477         0.0003         0.0115         0.0000         0.0011           13 <t< th=""><th></th><th>Avg.</th><th>Diff.</th><th>Avg.</th><th>Diff.</th><th>Avg.</th><th>Diff.</th><th></th><th></th></t<>		Avg.	Diff.	Avg.	Diff.	Avg.	Diff.		
3         0.0100         0.0001         0.0477         0.0002         0.0115         0.0001           4         0.0100         0.0000         0.0476         0.0005         0.0114         0.0002           5         0.0101         0.0001         0.0474         0.0002         0.0113         0.0001           6         0.0100         0.0003         0.0477         0.0003         0.0114         0.0003           7         0.0098         0.0000         0.0478         0.0005         0.0114         0.0001           8         0.0100         0.0003         0.0476         0.0005         0.0114         0.0001           9         0.0102         0.0002         0.0477         0.0007         0.0113         0.0000           10         0.0102         0.0003         0.0479         0.0002         0.0113         0.0000           11         0.0101         0.0479         0.0001         0.0114         0.0002         0.0115           13         0.0101         0.0478         0.0002         0.0115         0.0000         0.0115           14         0.0100         0.0001         0.0474         0.0003         0.0115         0.0002         0.0114									
4       0.0100       0.0000       0.0476       0.0005       0.0114       0.0002         5       0.0101       0.0011       0.0474       0.0002       0.0113       0.0001         6       0.0100       0.0003       0.0477       0.0003       0.0114       0.0003         7       0.0098       0.0000       0.0478       0.0000       0.0115       0.0001         8       0.0100       0.0003       0.0476       0.0005       0.0114       0.0001         9       0.0102       0.0002       0.0477       0.0007       0.0113       0.0000         10       0.0102       0.0003       0.0479       0.0002       0.0114       0.0002         11       0.0101       0.0001       0.0479       0.0002       0.0114       0.0002         12       0.0102       0.0001       0.0479       0.0002       0.0115       0.0000         13       0.0101       0.0022       0.0477       0.0001       0.0115       0.0000         14       0.0100       0.0002       0.0477       0.0003       0.0115       0.0002         15       0.0099       0.0022       0.0474       0.0003       0.0115       0.0001	1	0.0100	0.0001	0.0474	0.0003	0.0113	0.0000		
5         0.0101         0.0014         0.0002         0.0113         0.0001           6         0.0100         0.0003         0.0477         0.0003         0.0114         0.0003           7         0.0098         0.0000         0.0478         0.0000         0.0115         0.0001           8         0.0100         0.0003         0.0476         0.0005         0.0114         0.0001           9         0.0102         0.0002         0.0477         0.0007         0.0113         0.0000           10         0.0102         0.0003         0.0479         0.0002         0.0114         0.0002           11         0.0101         0.0011         0.0479         0.0002         0.0114         0.0002           11         0.0101         0.0479         0.0002         0.0114         0.0002           12         0.0102         0.0011         0.478         0.0002         0.0115         0.0000           13         0.0101         0.0478         0.0003         0.0115         0.0000         0.001           14         0.0100         0.0002         0.0477         0.0004         0.0116         0.0001           15         0.0099         0.0002         <	_								
6       0.0100       0.0003       0.0477       0.0003       0.0114       0.0003         7       0.0098       0.0000       0.0478       0.0000       0.0115       0.0001         8       0.0100       0.0003       0.0476       0.0005       0.0114       0.0001         9       0.0102       0.0002       0.0477       0.0007       0.0113       0.0000         10       0.0102       0.0003       0.0479       0.0002       0.0113       0.0000         11       0.0101       0.0001       0.0479       0.0002       0.0114       0.0002         12       0.0102       0.0001       0.0479       0.0002       0.0115       0.0000         13       0.0101       0.0478       0.0002       0.0115       0.0000         14       0.0100       0.0002       0.0477       0.0001       0.0115       0.0000         14       0.0100       0.0002       0.0477       0.0003       0.0115       0.0002         15       0.0099       0.0002       0.0477       0.0003       0.0116       0.0001         16       0.0099       0.0002       0.0474       0.0003       0.0114       0.0001       14	2	0.0100	0.0001	0.0476	0.0001	0.0114	0.0001		
7         0.0098         0.0000         0.0478         0.0000         0.0115         0.0001           8         0.0100         0.0003         0.0476         0.0005         0.0114         0.0001           9         0.0102         0.0002         0.0477         0.0007         0.0113         0.0000           10         0.0102         0.0003         0.0479         0.0002         0.0113         0.0000           11         0.0101         0.0011         0.0479         0.0002         0.0115         0.0002           12         0.0102         0.0001         0.0478         0.0002         0.0115         0.0000           13         0.0101         0.0022         0.0477         0.0001         0.0115         0.0000           14         0.0100         0.0022         0.0477         0.0001         0.0115         0.0000           14         0.0100         0.0022         0.0477         0.0004         0.0116         0.0001           15         0.0099         0.0002         0.0474         0.0003         0.0115         0.0002           16         0.0099         0.0002         0.0474         0.0002         0.0114         0.0001           18	2 3	0.0100 0.0100	0.0001 0.0001	0.0476 0.0477	0.0001 0.0002	0.0114 0.0115	0.0001 0.0001		
8         0.0100         0.0003         0.0476         0.0005         0.0114         0.0001           9         0.0102         0.0002         0.0477         0.0007         0.0113         0.0000           10         0.0102         0.0003         0.0479         0.0002         0.0113         0.0000           11         0.0101         0.0011         0.0479         0.0002         0.0113         0.0000           12         0.0102         0.0001         0.0478         0.0002         0.0115         0.0000           13         0.0101         0.0478         0.0003         0.0115         0.0000         0.0115           14         0.0100         0.0002         0.0477         0.0001         0.0115         0.0000           14         0.0100         0.0002         0.0477         0.0004         0.0116         0.0001           15         0.0099         0.0002         0.0474         0.0003         0.0115         0.0002           16         0.0099         0.0002         0.0474         0.0002         0.0114         0.0001           18         0.0101         0.0474         0.0002         0.0114         0.0000         0.0001           20	2 3 4	0.0100 0.0100 0.0100	0.0001 0.0001 0.0000	0.0476 0.0477 0.0476	0.0001 0.0002 0.0005	0.0114 0.0115 0.0114	0.0001 0.0001 0.0002		
9         0.0102         0.0002         0.0477         0.0007         0.0113         0.0000           10         0.0102         0.0003         0.0479         0.0002         0.0113         0.0000           11         0.0101         0.0001         0.0479         0.0001         0.0114         0.0002           12         0.0102         0.0001         0.0478         0.0002         0.0115         0.0000           13         0.0101         0.0022         0.0477         0.0001         0.0115         0.0000           14         0.0100         0.0002         0.0477         0.0001         0.0115         0.0000           14         0.0100         0.0002         0.0477         0.0004         0.0116         0.0001           15         0.0099         0.0002         0.0477         0.0004         0.0116         0.0001           16         0.0099         0.0002         0.0474         0.0003         0.0114         0.0001           17         0.0100         0.0004         0.0474         0.0002         0.0114         0.0001           18         0.0101         0.0474         0.0002         0.0114         0.0000         0.0001           20	2 3 4 5	0.0100 0.0100 0.0100 0.0101	0.0001 0.0001 0.0000 0.0001	0.0476 0.0477 0.0476 0.0474	0.0001 0.0002 0.0005 0.0002	0.0114 0.0115 0.0114 0.0113	0.0001 0.0001 0.0002 0.0001		
10       0.0102       0.0003       0.0479       0.0002       0.0113       0.0000         11       0.0101       0.0001       0.0479       0.0001       0.0114       0.0002         12       0.0102       0.0001       0.0478       0.0002       0.0115       0.0000         13       0.0101       0.0002       0.0477       0.0001       0.0115       0.0000         14       0.0100       0.0000       0.0478       0.0003       0.0115       0.0000         14       0.0100       0.0000       0.0478       0.0003       0.0115       0.0000         15       0.0099       0.0002       0.0477       0.0004       0.0116       0.0001         16       0.0099       0.0002       0.0474       0.0003       0.0114       0.0001         18       0.0101       0.0474       0.0002       0.0114       0.0001       0.0001         19       0.0100       0.0004       0.0474       0.0002       0.0114       0.0000       0.0001         20       0.0098       0.0000       0.0474       0.0002       0.0114       0.0000       0.0001         Max       0.0004       0.0474       0.0007       0.0003       0.011	2 3 4 5 6	0.0100 0.0100 0.0100 0.0101 0.0100	0.0001 0.0001 0.0000 0.0001 0.0003	0.0476 0.0477 0.0476 0.0474 0.0477	0.0001 0.0002 0.0005 0.0002 0.0002	0.0114 0.0115 0.0114 0.0113 0.0114	0.0001 0.0001 0.0002 0.0001 0.0003		
11       0.0101       0.0001       0.0479       0.0001       0.0114       0.0002         12       0.0102       0.0001       0.0478       0.0002       0.0115       0.0000         13       0.0101       0.0002       0.0477       0.0001       0.0115       0.0000         14       0.0100       0.0000       0.0478       0.0003       0.0115       0.0000         15       0.0099       0.0002       0.0477       0.0004       0.0116       0.0001         16       0.0099       0.0002       0.0474       0.0003       0.0115       0.0002         17       0.0100       0.0011       0.0474       0.0002       0.0114       0.0001         18       0.0101       0.0044       0.0474       0.0002       0.0114       0.0001         19       0.0100       0.0004       0.0474       0.0002       0.0114       0.0000         20       0.0098       0.0000       0.0474       0.0002       0.0114       0.0000         Max       0.0004       0.0474       0.0002       0.0114       0.0003       0.0003	2 3 4 5 6 7	0.0100 0.0100 0.0100 0.0101 0.0100 0.0098	0.0001 0.0001 0.0000 0.0001 0.0003 0.0000	0.0476 0.0477 0.0476 0.0474 0.0477 0.0478	0.0001 0.0002 0.0005 0.0002 0.0003 0.0003	0.0114 0.0115 0.0114 0.0113 0.0114 0.0114	0.0001 0.0001 0.0002 0.0001 0.0003 0.0001		
12       0.0102       0.0001       0.0478       0.0002       0.0115       0.0000         13       0.0101       0.0002       0.0477       0.0001       0.0115       0.0000         14       0.0100       0.0000       0.0478       0.0003       0.0115       0.0000         15       0.0099       0.0002       0.0477       0.0004       0.0116       0.0001         16       0.0099       0.0002       0.0474       0.0003       0.0115       0.0002         17       0.0100       0.0001       0.0474       0.0002       0.0114       0.0001         18       0.0101       0.00474       0.0002       0.0114       0.0000       0.0001         19       0.0100       0.0004       0.0474       0.0002       0.0114       0.0000         20       0.0098       0.0000       0.0474       0.0002       0.0114       0.0000         Max       0.0004       0.0474       0.0002       0.0114       0.0000       0.0003	2 3 4 5 6 7 8 9	0.0100 0.0100 0.0101 0.0101 0.0100 0.0098 0.0100 0.0102	0.0001 0.0001 0.0000 0.0001 0.0003 0.0000 0.0003 0.0002	0.0476 0.0477 0.0476 0.0474 0.0477 0.0478 0.0476 0.0477	0.0001 0.0002 0.0005 0.0002 0.0003 0.0000 0.0005 0.0007	0.0114 0.0115 0.0114 0.0113 0.0114 0.0115 0.0114 0.0113	0.0001 0.0001 0.0002 0.0001 0.0003 0.0001 0.0001		
13         0.0101         0.0002         0.0477         0.0001         0.0115         0.0000           14         0.0100         0.0000         0.0478         0.0003         0.0115         0.0000           15         0.0099         0.0002         0.0477         0.0004         0.0116         0.0001           16         0.0099         0.0002         0.0474         0.0003         0.0115         0.0002           17         0.0100         0.0001         0.0474         0.0003         0.0114         0.0001           18         0.0101         0.00474         0.0002         0.0114         0.0001         0.0011           19         0.0100         0.0044         0.0474         0.0002         0.0114         0.0000           20         0.0098         0.0000         0.0474         0.0002         0.0114         0.0000           Max         0.0004         0.0474         0.0002         0.0114         0.00003         0.0003	2 3 4 5 6 7 8 9	0.0100 0.0100 0.0101 0.0101 0.0100 0.0098 0.0100 0.0102	0.0001 0.0001 0.0000 0.0001 0.0003 0.0000 0.0003 0.0002	0.0476 0.0477 0.0476 0.0474 0.0477 0.0478 0.0476 0.0477	0.0001 0.0002 0.0005 0.0002 0.0003 0.0000 0.0005 0.0007	0.0114 0.0115 0.0114 0.0113 0.0114 0.0115 0.0114 0.0113	0.0001 0.0002 0.0001 0.0003 0.0001 0.0001 0.0001		
14       0.0100       0.0000       0.0478       0.0003       0.0115       0.0000         15       0.0099       0.0002       0.0477       0.0004       0.0116       0.0001         16       0.0099       0.0002       0.0474       0.0003       0.0115       0.0002         17       0.0100       0.0001       0.0474       0.0003       0.0114       0.0001         18       0.0101       0.0003       0.0474       0.0002       0.0114       0.0001         19       0.0100       0.0004       0.0474       0.0002       0.0114       0.0000         20       0.0098       0.0000       0.0474       0.0002       0.0114       0.0000         Max       0.0004       0.0474       0.0007       0.0003       0.0003       0.0003	2 3 4 5 6 7 8 9 10 11	0.0100 0.0100 0.0101 0.0101 0.0100 0.0098 0.0100 0.0102 0.0102	0.0001 0.0001 0.0000 0.0001 0.0003 0.0000 0.0003 0.0002 0.0002	0.0476 0.0477 0.0476 0.0474 0.0477 0.0478 0.0476 0.0477 0.0479 0.0479	0.0001 0.0002 0.0005 0.0002 0.0003 0.0000 0.0005 0.0007 0.0002 0.0001	0.0114 0.0115 0.0114 0.0113 0.0114 0.0115 0.0114 0.0113 0.0113	0.0001 0.0002 0.0001 0.0003 0.0001 0.0001 0.0000 0.0000		
15         0.0099         0.0002         0.0477         0.0004         0.0116         0.0001           16         0.0099         0.0002         0.0474         0.0003         0.0115         0.0002           17         0.0100         0.0001         0.0474         0.0003         0.0114         0.0001           18         0.0101         0.0003         0.0474         0.0002         0.0114         0.0001           19         0.0100         0.0004         0.0474         0.0002         0.0114         0.0000           20         0.0098         0.0000         0.0474         0.0002         0.0114         0.0000           40         0.0004         0.0474         0.0002         0.0114         0.0000         0.0001           19         0.0100         0.0004         0.0474         0.0002         0.0114         0.0000         0.0001           20         0.0098         0.0000         0.0474         0.0002         0.0114         0.0000         0.0003         0.0003         0.0003         0.0003         0.0003         0.0003         0.0003         0.0003         0.0003         0.0003         0.0003         0.0003         0.0003         0.0003         0.0003         0.0003	2 3 4 5 6 7 8 9 10 11	0.0100 0.0100 0.0101 0.0101 0.0100 0.0098 0.0100 0.0102 0.0102 0.0101	0.0001 0.0001 0.0000 0.0001 0.0003 0.0000 0.0003 0.0002 0.0003 0.0003 0.0003	0.0476 0.0477 0.0476 0.0474 0.0477 0.0478 0.0476 0.0477 0.0479 0.0479	0.0001 0.0002 0.0005 0.0002 0.0003 0.0000 0.0005 0.0007 0.0002 0.0001	0.0114 0.0115 0.0114 0.0113 0.0114 0.0115 0.0114 0.0113 0.0113 0.0114	0.0001 0.0002 0.0001 0.0003 0.0001 0.0001 0.0000 0.0000 0.0000		
16       0.0099       0.0002       0.0474       0.0003       0.0115       0.0002         17       0.0100       0.0001       0.0474       0.0003       0.0114       0.0001         18       0.0101       0.0003       0.0474       0.0002       0.0114       0.0001         19       0.0100       0.0004       0.0474       0.0002       0.0114       0.0000         20       0.0098       0.0000       0.0474       0.0002       0.0114       0.0000         Max       0.0004       0.0474       0.0007       0.0003       0.0003       0.0003	2 3 4 5 6 7 8 9 10 11 12 13	0.0100 0.0100 0.0101 0.0101 0.0100 0.0098 0.0100 0.0102 0.0102 0.0101 0.0102 0.0102 0.0101	0.0001 0.0001 0.0000 0.0003 0.0000 0.0003 0.0002 0.0003 0.0001 0.0001	0.0476 0.0477 0.0476 0.0474 0.0477 0.0478 0.0476 0.0477 0.0479 0.0479 0.0478	0.0001 0.0002 0.0005 0.0002 0.0003 0.0000 0.0005 0.0007 0.0007 0.0002 0.0001 0.0002 0.0001	0.0114 0.0115 0.0114 0.0113 0.0114 0.0115 0.0114 0.0113 0.0113 0.0114 0.0115 0.0115	0.0001 0.0002 0.0001 0.0003 0.0001 0.0001 0.0000 0.0000 0.0002 0.0000		
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#### Table 2 Repeatability test results



Qualitative scans of each analyte element are shown in Figure 2 and demonstrate the excellent signal-to-noise and spectral resolution of the wavelength-dispersive technology in the Rigaku Supermini200.

#### Conclusions

This application note demonstrates that lubricating oils and additives can be routinely analyzed with excellent accuracy, sensitivity and repeatability using a benchtop WDXRF spectrometer with minimal site requirements. In particular, the Rigaku Supermini200 sequential WDXRF system meets the specifications of ASTM D6443-04, as well as those of ASTM D4927-05, which applies to higher concentrations of additive elements.

#### Reference

ASTM D6443-04 (2010) Standard Test Method for Determination of Calcium, Chlorine, Copper, Magnesium, Phosphorus, Sulfur, and Zinc in Unused Lubricating Oils and Additives by Wavelength Dispersive X-ray Fluorescence Spectrometry (Mathematical Correction Procedure)



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