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Ms. Nadia Hollan
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Subject: Data Summary Report for the Characterization of Vat Leach Tailings Using X-Ray Fluorescence, Yerington Mine Site, Lyon County, Nevada: Administrative Order on Consent, EPA Docket No. 09-2009-0010

Dear Ms. Hollan:

Pursuant to the revised VLT Characterization Work Plan Using X-Ray Fluorescence (XRF Work Plan; Brown and Caldwell, 2009a) dated November 13, 2009, and subsequent correspondence and discussions with the U.S. Environmental Protection Agency - Region 9 (EPA) including a letter from EPA dated March 18, 2010 and a technical meeting held on July 15, 2010, the Atlantic Richfield Company (ARC) has prepared this *Data Summary Report for the Characterization of Vat Leach Tailings Using X-Ray Fluorescence, Yerington Mine Site* (VLT XRF DSR). Pending EPA review, the information presented in this VLT XRF DSR may be used to support the placement of interim covers over the Thumb Pond and Sub-Area A, which are former Anaconda evaporation ponds located on the Yerington Mine Site (Site) in Lyon County, Nevada. The interim covers were designated as removal actions required under the Administrative Order on Consent (AOC) and associated Scope of Work (SOW)¹ dated April 21, 2009 (effective May 1, 2009). The Site location is shown in Figure 1. The SOW states that:

Respondent (ARC) shall provide and implement a design plan to limit the ponding of low pH, metalliferous water in the lined evaporation ponds to the northwest within the Site to prevent to the extent feasible threats to wildlife as determined by EPA. The design plan also shall include proposed measures to limit the migration of dust containing hazardous substances from the lined and unlined evaporation ponds to the northwest within the Site and those areas known as the "Thumb Pond" and the "Sulfide Tailings Area".

Respondent shall submit a design plan that shall include the use of Vat Leach Tails (VLT) fill material. Respondent shall also submit an implementation work plan for the construction of a VLT cap to be installed over the lined and unlined evaporation ponds, including enhancing the deteriorated cap at the Thumb Pond and capping the area identified as Sub-Area A. The thickness of the VLT cap shall be sufficient to mitigate standing water within the lined evaporation ponds, and to mitigate the generation of fugitive dust from the underlying sediments in the lined, unlined, Thumb Pond and Sub-Area A in Figure 1. The average thickness of the VLT cap will be 18 inches. Portions of the VLT cap may be thicker or thinner than 18 inches as appropriate based on engineering and design requirements to meet the stated objectives. Finally, Respondent shall submit a removal action report after completion of the work.

¹ Administrative Order on Consent and Settlement Agreement for Removal Action and Past Response Costs Anaconda Copper Mine, Yerington Nevada; U.S. EPA Region IX; CERCLA Docket No. 09-2009-0010.



DSR Content

This VLT XRF DSR includes the following sections:

- Removal Action Project Areas
- VLT Materials
- Characterization Objectives
- FPXRF Instrument
- Summary of Field Activities
- FPXRF Measurements
- Laboratory Analytical Data
- Comparison of FPXRF and Laboratory Data

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Removal Action Project Areas

ARC submitted the *Implementation Work Plan - Revision 1 Anaconda Evaporation Pond Removal Action (Thumb Pond and Sub-Area A)* dated June 18, 2010 (Brown and Caldwell, 2010). This revised Implementation Work Plan presented the revised geometry of the two VLT borrow source areas, which were greatly reduced in size and volume (approximately 13 percent) from the borrow areas intended to be characterized pursuant to the XRF Work Plan. EPA and ARC discussed this reduced volume relative to the sample locations presented in the XRF Work Plan on April 23, 2010, and agreed that the original 24 sample locations (with two samples at each location) would provide a more statistically valid data set for the potential use of XRF as a screening tool during the removal action.

The locations of the Thumb Pond and Sub-Area A, and the two VLT borrow areas (north and south), are shown on Figure 2 (presented as Figure 5-1 in the revised Implementation Work Plan). Figure 2 also depicts the original outline of the borrow source areas, which provided the basis for the number of samples presented in the XRF Work Plan. Figures 3 and 4, respectively, show the locations and designations for VLT samples collected from the north and south borrow areas.

VLT Materials

As indicated in the XRF Work Plan, VLT materials are believed to be generally homogeneous with localized differences in geotechnical and geochemical characteristics. Such differences in these spent ore materials likely result from different oxide ore types mined and leached by Anaconda and potential variations in the ore beneficiation steps. Recent particle size distribution testing of VLT materials (Brown and Caldwell, 2010) indicates they are composed of the following percentages of sand, gravel and fines:

- sand (fine to coarse grained) – about 45 percent;
- gravel (fine [3/4-inch minus]) – approximately 40 percent; and
- fines (silt and clay particles) – remaining 15 percent.

Visual observations of VLT materials indicate: 1) localized surface coatings of green-and white-colored copper and aluminum hydroxides; and 2) very localized occurrences of 'iron-bleed tailings' or 'red dust', a fine-grained precipitate from the vat leaching of the oxide ores. Table 1, reproduced and modified from the *Anaconda Evaporation Ponds Removal Action Characterization Data Summary Report - Revision 1* dated October 15, 2009 (RAC DSR; Brown and Caldwell, 2009b), presents previously available VLT whole rock chemical data. These data were collected by SRK Consulting on behalf of the Nevada Division of Environmental Protection (NDEP) in support of a previous removal action that used VLT materials to cover select areas on the Site with surface exposures of 'red dust'.

Characterization Objectives

As stated in the XRF Work Plan, the field and analytical activities described herein were designed to: 1) further characterize the VLT materials beyond the limited data set presented in Table 1; 2) determine if any statistically viable correlations exist between XRF measurements of metals concentrations obtained with a field portable XRF (FPXRF) instrument and laboratory analyses of metal concentrations using EPA Methods 6010B, 6020, and 7471A (FPXRF instruments do not measure all the metals that can be analyzed in the laboratory, nor do they measure radiochemicals such as uranium and thorium); and 3) provide the basis, if any, to eliminate the use of 'anomalous' VLT (i.e., VLT with metal concentrations above to-be-determined threshold values) as interim cover materials. If used during the removal action, EPA and ARC would further discuss how to implement the field screening of VLT materials using the FPXRF instrument.

Summary of Field Activities

VLT characterization field activities were implemented as described in the XRF Work Plan, in accordance with the updated *Site-wide Quality Assurance Project Plan* (QAPP - Revision 5; ESI and Brown and Caldwell, 2009). Hand auger soil samples were collected between May 11 and 13, 2010. Twenty locations were situated in the north borrow area shown on Figure 3, and four locations were situated in the south borrow area shown on Figure 4. At each location, samples were generally collected from 0.5-1.0 ft bgs and from 2.5-3.0 feet below ground surface (feet bgs). The shallow sample interval was designated as "A" and the deeper interval was designated as "B". At one sample location (VLT-XRF-15), an additional "C" interval sample was collected from 1.75-2.25 feet bgs to assess potential geochemical differences between VLT materials with red dust observed at that depth and the gray-colored VLT materials observed in the shallow and deeper sample intervals at this and other locations. In all, a total of 49 primary VLT samples were collected for characterization. Attachment A provides photographs and field notes for the sampling.

| Table 1. NDEP VLT Whole Rock Analytical Results | | | | | | | | | | | | | | | | | | | | | | | |
|---|----------|----------|---------|--------|-----------|---------|---------|----------|--------|--------|-------|-------|-----------|-----------|---------|--------|-----------|----------|--------|--------|----------|----------|-------|
| Sample Name | Metals | | | | | | | | | | | | | | | | | | | | | | |
| | Aluminum | Antimony | Arsenic | Barium | Beryllium | Cadmium | Calcium | Chromium | Cobalt | Copper | Iron | Lead | Magnesium | Manganese | Mercury | Nickel | Potassium | Selenium | Silver | Sodium | Thallium | Vanadium | Zinc |
| | mg/ka | mg/ka | mg/ka | mg/ka | mg/ka | mg/ka | mg/ka | mg/ka | mg/ka | mg/ka | mg/ka | mg/ka | mg/ka | mg/ka | mg/ka | mg/ka | mg/ka | mg/ka | mg/ka | mg/ka | mg/ka | mg/ka | mg/ka |
| YVLT1-1 | | | | | | | | | | | | | | | | | | | | | | | |
| Result | 10000 | 4.85 | 11.8 | 69.6 | <0.40 | <0.40 | 7320 | 5.90 | <4.00 | 2290 | 17700 | 8.75 | 8110 | 58.4 | 1.85 | 8.28 | 888 | 5.21 | <2.00 | 248 | <0.20 | 27.2 | 18.6 |
| Detection Limit | 4.00 | 0.60 | 1.00 | 4.00 | 0.40 | 0.40 | 100 | 1.00 | 4.00 | 2.00 | 200 | 1.40 | 20.0 | 1.0 | 0.020 | 4.00 | 500 | 2.00 | 2.00 | 100 | 0.20 | 4.00 | 10.0 |
| YVLT1-2 | | | | | | | | | | | | | | | | | | | | | | | |
| Result | 7910 | 3.45 | 8.95 | 73.5 | <0.40 | <0.40 | 5690 | 6.06 | <4.00 | 1590 | 20900 | 8.75 | 5960 | 58.9 | 0.449 | 7.14 | 992 | 4.01 | <2.00 | 136 | 0.21 | 24.3 | 22.4 |
| Detection Limit | 4.00 | 0.60 | 1.00 | 4.00 | 0.40 | 0.40 | 100 | 1.00 | 4.00 | 2.00 | 200 | 1.40 | 20.0 | 1.0 | 0.020 | 4.00 | 500 | 2.00 | 2.00 | 100 | 0.20 | 4.00 | 10.0 |
| YVLT1-2 DUPLICATE | | | | | | | | | | | | | | | | | | | | | | | |
| Result | 8840 | 3.24 | 12.8 | 73.8 | <0.40 | <0.40 | 5890 | 6.99 | <4.00 | 1780 | 26100 | 9.88 | 6480 | 63.6 | 0.412 | 8.08 | 1080 | 4.23 | <2.00 | 138 | <0.20 | 28.6 | 24.9 |
| Detection Limit | 4.00 | 0.60 | 1.00 | 4.00 | 0.40 | 0.40 | 100 | 1.00 | 4.00 | 2.00 | 200 | 1.40 | 20.0 | 1.0 | 0.020 | 4.00 | 500 | 2.00 | 2.00 | 100 | 0.20 | 4.00 | 10.0 |
| YVLT1-3 | | | | | | | | | | | | | | | | | | | | | | | |
| Result | 8690 | 2.78 | 12.3 | 82.7 | <0.40 | <0.40 | 6010 | 4.92 | <4.00 | 2390 | 23000 | 6.94 | 6780 | 86.1 | 0.538 | 7.89 | 709 | 2.48 | <2.00 | 157 | <0.20 | 24.5 | 23.6 |
| Detection Limit | 4.00 | 0.60 | 1.00 | 4.00 | 0.40 | 0.40 | 100 | 1.00 | 4.00 | 2.00 | 200 | 1.40 | 20.0 | 1.0 | 0.020 | 4.00 | 500 | 2.00 | 2.00 | 100 | 0.20 | 4.00 | 10.0 |
| YVLT3-1 | | | | | | | | | | | | | | | | | | | | | | | |
| Result | 5930 | 5.41 | 10.7 | 59.2 | <0.40 | <0.40 | 7090 | 4.62 | <4.00 | 1410 | 13300 | 8.04 | 6111 | 45.9 | 0.619 | 6.89 | 862 | 5.53 | <2.00 | 149 | 0.226 | 16.1 | 15.1 |
| Detection Limit | 4.00 | 0.60 | 1.00 | 4.00 | 0.40 | 0.40 | 100 | 1.00 | 4.00 | 2.00 | 200 | 1.40 | 20.0 | 1.0 | 0.020 | 4.00 | 500 | 2.00 | 2.00 | 100 | 0.20 | 4.00 | 10.0 |
| YVLT3-2 | | | | | | | | | | | | | | | | | | | | | | | |
| Result | 6380 | 3.47 | 14.3 | 68.6 | <0.40 | <0.40 | 6170 | 6.93 | <4.00 | 928 | 17100 | 8.83 | 6560 | 44.3 | 0.488 | 9.58 | 1210 | 5.01 | <2.00 | <100 | 0.363 | 24.4 | 15.3 |
| Detection Limit | 4.00 | 0.60 | 1.00 | 4.00 | 0.40 | 0.40 | 100 | 1.00 | 4.00 | 2.00 | 200 | 1.40 | 20.0 | 1.0 | 0.020 | 4.00 | 500 | 2.00 | 2.00 | 100 | 0.20 | 4.00 | 10.0 |
| YVLT3-2 DUPLICATE | | | | | | | | | | | | | | | | | | | | | | | |
| Result | 6500 | 3.52 | 17.7 | 70.1 | <0.40 | <0.40 | 5830 | 6.70 | <4.00 | 837 | 16700 | 9.62 | 6690 | 45.3 | 0.490 | 10.5 | 1280 | 5.19 | <2.00 | <100 | 0.60 | 24.8 | 15.0 |
| Detection Limit | 4.00 | 0.60 | 1.00 | 4.00 | 0.40 | 0.40 | 100 | 1.00 | 4.00 | 2.00 | 200 | 1.40 | 20.0 | 1.0 | 0.020 | 4.00 | 500 | 2.00 | 2.00 | 100 | 0.20 | 4.00 | 10.0 |
| YVLT3-3 | | | | | | | | | | | | | | | | | | | | | | | |
| Result | 6730 | 1.73 | 19.6 | 59.0 | <0.40 | <0.40 | 7780 | 6.33 | <4.00 | 1530 | 22400 | 10.1 | 5990 | 46.9 | 0.354 | 8.77 | 1250 | 8.61 | <2.00 | 153 | 0.46 | 29.7 | 20.1 |
| Detection Limit | 4.00 | 0.60 | 1.00 | 4.00 | 0.40 | 0.40 | 100 | 1.00 | 4.00 | 2.00 | 200 | 1.40 | 20.0 | 1.0 | 0.020 | 4.00 | 500 | 2.00 | 2.00 | 100 | 0.20 | 4.00 | 10.0 |

Sample Collection Methods

Samples were collected using a hand auger equipped with a 3-inch diameter by approximately 8-inch long auger bucket. The auger was decontaminated between sampling of each interval and after sampling of each location utilizing a three-step decontamination process consisting of an alconox soap wash and two separate rinses of distilled water (Attachment A). Sample materials contained in the auger bucket were transferred into one-gallon Ziploc bags at each boring location. Each sample was labeled "VLT-XRF-#A", where the "#" identified the sample location (1 – 24) and the last letter (A, B, or C) indicated the sample depth. Sample bags were placed into an ice chilled cooler and subsequently transferred to a field office refrigerator at the end of each work day.

Each sample was homogenized by hand tumbling the Ziploc bag. A homogenized sub-sample was then removed from the Ziplock bag and placed in an 8-ounce plastic non-preserved jar for analysis of total metals at the project laboratory using EPA Methods 6010B, 6020, and 7471A (EPA, 2007). All laboratory samples were packed and shipped on ice overnight to the TestAmerica laboratory in Richland, Washington for sample preparation including grinding and homogenization. The TestAmerica Richland lab analyzed uranium and thorium by ICP-MS (Method 6020) and submitted an aliquot of the prepared sample to the TestAmerica Irvine laboratory for the metals analyses. Sample materials remaining in the Ziploc bags were securely stored on-Site for subsequent XRF measurements and possible future use. Metal and radiochemical analytical results are provided in Appendix D. Although uranium and thorium data were collected to more comprehensively characterize VLT materials, the XRF instrument does not detect these analytes and these data are not discussed in this VLT XRF DSR.

Laboratory Quality Control Samples

In addition to the primary VLT samples described above, a series of quality control (QC) samples were also collected. The QC samples consisted of the following:

- Field Duplicate Samples - A duplicate soil sample was collected from every 5th interval, which ensured that duplicate samples were obtained from alternating shallow and deep intervals. These samples were labeled as VLT-XRF-DUP1 through VLT-XRF-DUP10.
- Equipment Blanks - An equipment blank was collected daily from the hand auger by pouring laboratory pure deionized (DI) water over the decontaminated auger bucket and collecting the water in plastic 250 ml bottle preserved with HNO₃. One equipment blank was also collected from a new 1-gallon Ziploc bag by pouring laboratory pure DI water in the bag and then transferring it into a HNO₃-preserved plastic 250 ml bottle. The equipment blanks were labeled VLT-XRF-EB 1 through VLT-XRF-EB 4.

FPXRF Instrument

The FPXRF instrument selected to perform the field measurements described herein was an Innov-X Handheld energy dispersive XRF (EDXRF), which uses a powerful, miniature X-ray tube excitation source and a high resolution silicon PIN diode detector to improve performance and provide a lower level of detection (LOD) than most other commercially available FPXRF instruments. As described in EPA Method 6200 (EPA, 2007), the FPXRF instrument sensitivity and LODs that can be achieved under actual field conditions depend on a number of factors including the analyte(s) of interest, the type and strength (i.e., power output) of the excitation source, the type of detector used, the position of the FPXRF during measurements, the measurement duration, physical matrix effects, chemical matrix effects (i.e., inter-elemental spectral interferences), and moisture effects.

The LODs that were presented in the XRF Work Plan for the metals analyses using the FPXRF under interference-free conditions are summarized below, along with the actual LODs obtained while performing field measurements:

| <u>Metals</u> | Potential Interference-Free <u>LODs (ppm)</u> | Actual Field <u>LODs (ppm)</u> |
|---------------|---|--------------------------------------|
| Antimony | 30 – 50 | 46 – 63 |
| Arsenic | 7 – 10 | 3 – 11 |
| Barium | 150 – 200 | 129 – 271 |
| Cadmium | 15 – 20 | 25 – 35 |
| Chromium | 30 – 50 | 47 – 101 |
| Copper | 15 – 20 | 12 – 13 |
| Lead | 10 – 15 | 4 – 7 |
| Mercury | 10 – 15 | 5 – 9 |
| Nickel | 20 – 25 | 21 – 38 |
| Selenium | 7 – 10 | 2 – 3 |
| Silver | 15 – 20 | 24 – 34 |
| Thallium | 10 – 15 | Not Analyzed |
| Tin | 30 – 50 | 42 – 57 |
| Zinc | 15 – 20 | 5 – 17 |

This comparison indicates that the actual range of LODs associated with field measurements was comparable to, or lower than, the potential range identified in the XRF Work Plan for arsenic, copper, lead, mercury, selenium and zinc. Actual ranges for antimony, cadmium, chromium, silver and tin were consistently higher than the potential range. For barium and nickel, the lower end of each actual range was less than or comparable to that of the potential range, while the upper end of the actual range for both metals was higher than the upper bound of the potential range.

As stated in the XRF Work Plan, potential errors associated with the FPXRF instrument would not be as significant as user- or application-specific factors such as measurement duration, physical matrix effects, chemical matrix effects, and moisture effects. These field-related factors may result in data variability that can adversely affect the correlation between instrument readings and laboratory analytical results. EPA Method 6200 describes procedures to minimize the cumulative impact of these potential errors, which were described in the XRF Work Plan and implemented during the FPXRF measurements described below. User-specific factors include separation distance and measurement duration. Potential error increases in direct relation to the separation distance between the instrument and the sample. Therefore, minimizing this error was accomplished by keeping the FPXRF probe window in direct contact with the sample bag whenever a measurement was taken, as shown in Figure 5.

Precision Optimization

Measurement duration affects the precision and detection limits of each result. Increasing the measurement duration by a factor of four will improve precision by a factor of two and will improve detection limits by 50 percent (EPA Method 6200). The following optimization steps were performed at prior to the start of VLT field screening to determine the optimal measurement duration:

1. One of the four quadrants of a flat-lying zip-lock bag containing VLT sample materials is used for all of the optimization measurements; only copper measurements are used.
2. A series of 10 FPXRF measurements is taken and recorded on a field form at each of four progressively longer measurement durations consisting of 60, 80, 100 and 120 seconds.
3. Summary statistics including mean, standard deviation (SD), variance (V), and coefficient of variation (CV) are then be calculated for the 10 FPXRF measurements taken at each of the four measurement durations. SD, V, and CV values calculated for each of the four sets of FPXRF measurements are be plotted versus the corresponding measurement duration.

4. A best fit trend line is then fitted to the plotted data points for each parameter (SD, V, and CV), and the approximate inflection point (i.e., the trend line where a change in slope indicates that the measurement duration no longer affects the measurements) is identified (if present).
5. The measurement duration to be used for subsequent FPXRF field screening is the longest time associated with the inflection point of the trend line for any of the three plotted statistical parameters (if only one inflection point is identified, that value will be used). If no obvious inflection point can be identified, 120 seconds is used for the FPXRF field screening process.

These precision optimization procedures for measurement duration were performed on a single quadrant of VLT material sample VLT-XRF-24B (each sample bag was divided into four quadrants, as shown on Figure 6). A summary of the precision optimization findings is presented in Attachment B. Plots of the standard deviation, variance and coefficient of variation versus the measurement time intervals did not exhibit a consistent trend that yielded a suitable measurement duration inflection point. However, the results indicated that the 120-second time interval provided results that most closely conformed to the overall mean of all precision optimization measurements and exhibited the least amount of data scatter relative to the mean. Based on this evaluation, the 120-second time interval was selected as the duration for subsequent FPXRF measurements of the VLT samples.

Physical Matrix Effects

Physical matrix effects result from variations in the physical characteristics of the sample material (e.g., particle size, homogeneity, and surface conditions). Because XRF is a surface analytical method (i.e., the measurement only represents conditions on the surface of the sample particles) that measures an approximate one square centimeter area (i.e., a small portion of the overall sample area), this technique can be more sensitive to sample heterogeneity than standard laboratory analytical methods. Given that the variability of XRF results associated with sample heterogeneity would be most significant for in-situ measurements, each VLT sample was evenly distributed in a one-gallon plastic bag before FPXRF measurements were taken to provide uniform surface conditions for the measurements.

Chemical Matrix Effects

Chemical matrix effects result from interactions between fluorescent X-rays from different elements, which can occur as spectral interferences (peak overlaps) or X-ray absorption and enhancement phenomena. Both effects are common in soils containing heavy metals. One of the most common peak overlaps is associated with high lead concentrations, which interferes with arsenic and typically results in an elevated arsenic LOD. Measured copper concentrations decrease in the presence of iron, which tends to absorb the copper X-rays. Conversely, measured chromium concentrations are enhanced in the presence of iron (EPA Method 6200). While these chemical matrix effects are generally addressed mathematically through the FPXRF instrument internal software, they are not eliminated. The Innov-X Handheld FPXRF used for the VLT materials is equipped with the internal software necessary for these mathematical corrections.

Moisture Effects

XRF measurements are more sensitive to moisture content than standard laboratory methods because XRF measures the bulk concentration of a sample's surface cross-section. When moisture content in a sample is less than approximately 15 percent, the magnitude of potential error is negligible. However, when moisture content is 15-20 percent or greater, XRF measurements are typically biased low (i.e., the reported concentration would be approximately 70 to 80 percent of what would be measured for a dry sample). Given the generally low moisture content of VLT materials (i.e., 4 to 7 percent moisture as described in the Implementation Work Plan - Revision 1 dated June 18, 2010 [Brown and Caldwell, 2010]), no adverse impacts on FPXRF measurements of VLT materials were anticipated except if the samples were collected during or after precipitation events. Given that the samples were collected after a number of days without precipitation and were observed to be dry, sample drying prior to FPXRF measurements was determined not to be necessary and was not performed.

FPXRF Measurements

The VLT sample materials remaining in the Ziploc bags were characterized on May 18-21, 2010 using the FPXRF instrument. FPXRF measurements of the VLT sample materials were obtained by laying the Ziploc bag containing the homogenized sample material on a flat non-metallic work bench, then dividing the flattened material into four quadrants. The quadrants were numbered 1 through 4 beginning in the top right corner and proceeding in a counter-clockwise direction (Figure 6), and a single 120-second measurement was made for each quadrant. The FPXRF measurement results were recorded by hand on field forms and stored electronically in the FPXRF analyzer iPAQ unit. A total of 196 FPXRF measurements were made for the 49 samples.

Quality Control Measurements

As specified in the XRF Work Plan, a series of QC measurements were taken and recorded in addition to the 196 primary measurements described above. QC measurements included energy calibration checks (i.e., standardization), instrument blank measurements, calibration verification checks, and precision measurements. Energy calibration checks were performed to verify that the FPXRF instrument was operating within resolution and stability tolerances established by the manufacturer. These calibration checks were performed at instrument power-up and after every 20th measurement, as described in the XRF Work Plan. Instrument blank measurements were made using a manufacturer-supplied pure SiO₂ "quartz/silica blank" block to verify the presence or absence of any foreign material (i.e., metals) on the XRF filter that could result in erroneous measurements. If a metal was detected, the FPXRF filter was cleaned with DI water and a paper towel, and then re-analyzed to verify the absence of any foreign material (i.e., results all below the level of detection) before proceeding to the next sample. An instrument blank measurement was performed on every 20th sample in accordance with the XRF Work Plan.

Calibration verification checks consisted of FPXRF measurements made using a standard reference material (SRM) containing certified amounts of metals to check the accuracy of the instrument and assess the stability and consistency of the analyses. A sample provided by the manufacturer was used for this purpose. Calibration verification checks were performed at the beginning and end of each day and after every 20th sample measurement, in accordance with the XRF Work Plan. Precision measurements evaluate the FPXRF analyzers ability to produce consistent results for multiple measurements of the same sample. Ten replicate measurements of the a VLT sample were taken at the beginning and end of each day, with precision assessed by calculating a relative standard deviation (RSD) of the replicate measurements for each analyte. Per EPA Method 6200, the RSD should not be greater than 20 percent for individual metals with the exception of chromium (the RSD for chromium should not exceed 30 percent). If RSD values above these thresholds were observed during field screening, the variation was to be noted but no corrective actions were taken at that time. However, RSD values above the thresholds would be considered during subsequent correlation of FPXRF and laboratory analytical data.

FPXRF Data

Summary statistics (frequency of detection, minimum, mean, and maximum) for the FPXRF measurement data representing the 49 primary VLT samples are presented in Table 2 below. Results of the VLT sample XRF measurements and QC XRF measurements are also summarized in Attachment C. Attachment C-1 provides a summary of the four quadrant XRF measurements made of each of the 49 VLT material samples. Attachment C-2 presents mean values (i.e., the average of the four individual quadrant measurements) for each sampled interval at each VLT sample location. Attachment C-3 is a summary of the QC measurements, and Attachment C-4 provides the precision measurement RSD values. Measurement values identified in Attachments C-1, C-3, and C-4 as "<LOD" indicate the reported value for that measurement was less than the level of detection for the FPXRF instrument. For all measurements identified as "<LOD", a value equal to the detection limit was assigned to that measurement so that mean sample values could be calculated based on the four quadrant measurements for each sample.

As the summary statistics in Table 2 and at the bottom of Attachment C-2 indicate, a high percentage of “<LOD” measurements were reported for cadmium, chromium, lead, mercury, manganese, molybdenum, nickel, silver, tin and zinc, while all of the antimony and cobalt measurements were “<LOD”. Conversely, no “<LOD” measurements were reported for the copper, iron, rubidium, strontium, titanium and zirconium XRF measurement results reported for the 49 VLT samples. As the summary statistics at the bottom of Attachment C-2 illustrate, the FPXRF measurement values for each metal analyzed from the 49 samples indicate that VLT materials exhibit relatively consistent concentrations. In addition, little or no difference in mean concentrations was observed between shallow (0.5-1.0 feet bgs) and deeper (2.5-3.0 feet bgs) samples. These mean values and the associated standard deviation values indicate that the VLT materials within the two borrow areas are, in general, chemically homogeneous and do not significantly vary between shallow and deeper sample depths.

One exception to the generally consistent concentrations observed in the FPXRF measurements was for the sample (VLT-XRF-15C) that contained red dust, which was collected from the 1.75-2.25 feet bgs interval. A comparison of the metals concentrations for this sample to the mean concentrations of each metal representing the other 48 samples indicates: 1) little or no difference in cadmium, mercury, molybdenum, selenium, silver, tin, titanium, and zinc concentrations; and 2) noticeable differences in arsenic, barium, cobalt, chromium, copper, iron, lead, manganese and nickel concentrations. The arsenic concentration from VLT-XRF-15C was twice the mean concentration in the other VLT samples, and the lead concentration was 1.5 times greater. Conversely, copper and iron concentrations from VLT-XRF-15C were 63 and 69 percent, respectively, of the mean value of the other samples. Concentrations of barium, cobalt, chromium, manganese and nickel from VLT-XRF-15C varied between 77 and 83 percent of the mean values for these metals from the remaining 48 samples.

The QC data summarized in Attachment C3 indicate good overall FPXRF instrument performance during the VLT sample measurements and, with a few exceptions, the precision measurement RSD values presented at the bottom of Attachment C4 were all less than the 20% threshold (30% for chromium) recommended for EPA Method 6200. The only exceptions were for arsenic, barium, lead, manganese, selenium, and zinc. For these metals, one or more of the four calculated RSD values exceeded the specified threshold. However, RSD values exceeding the threshold were generally only slightly above the threshold, within the range of 21 to 28 percent, with the highest value a 33 percent reported for lead. Where RSD values exceeding the 20% threshold are observed, the RSD value is generally associated with a 10 measurement data set that includes a mix of detected and “<LOD” values. Overall, the RSD results indicate good XRF measurement precision. For example, the calculated RSD values for copper from the four sets of precision measurements (2%, 17%, 1% and 2%) were all below the 20 percent threshold value.

Laboratory Analytical Data

VLT materials samples submitted to the project laboratory were analyzed for total metals using EPA Methods 6010B, 6020, and 7471A. Summary statistics (frequency of detection, minimum, mean, and maximum) for the laboratory analytical data representing the 49 primary VLT samples are presented in Table 2. Copies of the laboratory analytical reports for the 49 primary and 10 field duplicate VLT samples, as well as the equipment blank samples, are presented in Attachment D-1. A tabular summary of the laboratory analytical results for the VLT materials samples is presented in Attachment D-2 and a summary of the relative percent difference (RPD) calculations for primary and duplicate sample pairs is presented in Attachment D-3. As indicated above, radiochemical data results are not discussed herein, but are provided in Attachment D for future reference.

| Table 2. Comparison of XRF and Laboratory Data Summary Statistics | | | | | | | | |
|---|-----------------------------|---------------|--------------|--------------|--------------------------------|---------------|--------------|--------------|
| Metal | XRF Measurements (in mg/kg) | | | | Laboratory Analyses (in mg/kg) | | | |
| | Frequency of Detection | Minimum | Mean | Maximum | Frequency of Detection | Minimum | Mean | Maximum |
| Aluminum | — | — | — | — | 100% | 3300 | 7724 | 16000 |
| Antimony | 0% | <50 | <54 | <58 | 80% | <0.74 | 2.0 | 12 |
| Arsenic | 83% | <5 | 7.5 | 15 | 100% | 2.7 | 6.4 | 17 |
| Barium | 80% | 213 | 298 | 408 | 100% | 30 | 60 | 140 |
| Beryllium | — | — | — | — | 8% | <0.25 | 0.25 | 0.33 |
| Boron | — | — | — | — | 2% | <2.1 | 2.2 | 4.5 |
| Cadmium | 1% | <28 | 30 | 33 | 0% | <0.25 | <0.25 | <0.25 |
| Calcium | — | — | — | — | 100% | 1300 | 3245 | 6700 |
| Chromium | 1% | <70 | 80 | 101 | 100% | 11 | 23 | 40 |
| Cobalt | 0% | <8 | <11 | <14 | 100% | 2.1 | 3.9 | 9.6 |
| Copper | 100% | 733 | 1334 | 2437 | 100% | 530 | 997 | 1700 |
| Iron | 100% | 12622 | 18996 | 30354 | 100% | 7000 | 11955 | 19000 |
| Lead | 71% | <6 | 8 | 12 | 100% | 2.1 | 3.3 | 5,7 |
| Magnesium | — | — | — | — | 100% | 2500 | 6137 | 12000 |
| Manganese | 24% | <52 | 62 | 93 | 100% | 26 | 46 | 75 |
| Mercury | 8% | <7 | 7.3 | 8 | 100% | 0.04 | 0.24 | 0.93 |
| Molybdenum | 12% | <14 | 16 | 18 | 100% | 1.2 | 3.3 | 5.5 |
| Nickel | 39% | <27 | 35 | 51 | 100% | 5.5 | 9 | 25 |
| Potassium | — | — | — | — | 100% | 440 | 1239 | 4200 |
| Rubidium | 100% | 24 | 45 | 72 | — | — | — | — |
| Selenium | 78% | <2 | 4.4 | 15 | 100% | 1.4 | 3.3 | 9.1 |
| Silver | 5% | <27 | 29 | 36 | 3% | <0.25 | 0.25 | 0.27 |
| Sodium | — | — | — | — | 100% | 76 | 145 | 380 |
| Strontium | 100% | 275 | 532 | 761 | — | — | — | — |
| Thallium | — | — | — | — | 15% | <0.49 | 0.58 | 1.6 |
| Tin | 1% | <47 | 49 | 53 | — | — | — | — |
| Titanium | 100% | 1562 | 2197 | 2997 | — | — | — | — |
| Vanadium | — | — | — | — | 100% | 12 | 23 | 55 |
| Zinc | 61% | <12 | 16 | 24 | 47% | <12 | 53 | 1800 |
| Zirconium | 100% | 75 | 93 | 124 | — | — | — | — |

Notes:

Summary statistics based on evaluation of 49 primary VLT samples analyzed using XRF and laboratory analytical methods
BOLD highlighted metals indicate the frequency of detection for both XRF and laboratory analyses is greater than or equal to 24 percent.
 These metals were evaluated further using scatter plots.
 — indicates the specified analyte was not analyzed using this analytical method
 mg/kg = milligrams per kilogram

Non-detect analytical results in Attachments D-2 and D-3 are identified by a "U" data qualifier, while results with a "J" data qualifier indicate estimated values that typically represent a detected result less than the method reporting limit. As indicated in Table 2 and at the bottom of Attachment D-2, 18 of the 25 metals analyzed by the laboratory had a 100 percent frequency of detection. Cadmium was not detected in any of the VLT samples analyzed by the laboratory. Beryllium, boron, silver, and thallium were only detected in 8, 2, 3, and 15 percent of the samples, respectively (Table 2).

A QC comparison of analytical results reported for primary samples and their associated field duplicates was conducted by calculating the RPD for each pair of primary-field duplicate results. Because RPD calculations require a numerical result for both the primary and duplicate samples being evaluated, non-detect sample results were assigned a value equal to the method detection limit as indicated in Attachment D-3. With a few exceptions, the RPD results of each primary/duplicate sample pair for each metal are generally less than 20 percent, which indicates good reproducibility between the primary and duplicate samples. The metal exhibiting the poorest RPD results was zinc. This is primarily attributed to the high frequency of estimated ("J" qualified) and non-detect ("U" qualified) results reported for this analyte. The good overall RPD results suggest that field sampling techniques are not a significant source of variability with the VLT materials samples data.

Laboratory results for equipment blank samples presented in Attachment D-1 indicate that with a few exceptions, metals evaluated in this technical memorandum were not detected in the equipment blanks. Metals reported in one or more of these four liquid QC samples were as follows:

- Barium – sample VLT-XRF-EB3 at 0.63 mg/L and sample VLT-XRF-EB4 at 0.32 mg/L
- Chromium – sample VLT-XRF-EB1 at 2.4 mg/L
- Copper – sample VLT-XRF-EB1 at 1.5 mg/L, sample VLT-XRF-EB2 at 1.3 mg/L, sample VLT-XRF-EB3 at 1.3 mg/L, and sample VLT-XRF-EB4 at 0.51 mg/L
- Iron – sample VLT-XRF-EB1 at 0.017 milligrams per liter (mg/L)
- Nickel – sample VLT-XRF-EB1 at 0.86 mg/L
- Zinc – sample VLT-XRF-EB2 at 9.0 mg/L and sample VLT-XRF-EB4 at 7.6 mg/L

The detected concentrations of barium, chromium, copper, iron, and nickel in the equipment blanks are far below the reported concentrations of these metals in the VLT materials samples, indicating that the VLT materials samples are not impacted by these detections in the blank samples. Although the two zinc concentrations detected in the equipment blanks are 63 to 75 percent of the minimum detection limit of zinc reported for the VLT materials samples, they are only 47 to 56 percent of the lowest zinc concentration reported for the VLT materials. As such, they are unlikely to have had any adverse impact on the VLT materials samples analytical results.

Comparison of FPXRF and Laboratory Data

A comparison of the FPXRF instrument measurements and laboratory analytical results is presented in Table 2. This comparison indicates that five metals (rubidium, strontium, tin, titanium and zirconium) included in the FPXRF measurements are not reported by the laboratory analytical methods while nine metals (aluminum, beryllium, boron, calcium, magnesium, potassium, sodium, thallium and vanadium) included in the laboratory analyses are not reported by the FPXRF detection method. Scatter plots and boxplots have been developed to illustrate the relationship between the XRF measurements and the laboratory analytical data for those metals common to both types of analyses. Of the 30 metals identified in Table 2, 16 are common to both FPXRF measurements and laboratory analytical methods. The list of metals suitable for use in correlating between FPXRF measurements and laboratory analytical methods is further reduced by the frequency of detection associated with each method.

As illustrated by the **bold** highlighted metals in Table 2, only 9 of the 16 metals common to both methods had a frequency of detection considered sufficient (i.e., greater than or equal to 24 percent) for direct correlation purposes. Of the 9 highlighted metals (arsenic, barium, copper, iron, lead, manganese, nickel, selenium, and zinc), only copper and iron were detected in 100 percent of the samples analyzed using both FPXRF and laboratory methods. The higher frequency of detection generally associated with the laboratory analytical data results from the lower detection limits associated with laboratory analytical methods relative to the level of detection achievable using the FPXRF instrument.

Scatter Plots

For the nine metals identified above with XRF and laboratory analytical frequencies of detection considered sufficient for correlation purposes, scatter plots of the mean sample FPXRF measurement values (i.e., mean of the 4 quadrant measurements for each sample) versus the corresponding laboratory analytical result were generated. In generating the scatter plots, only samples that had detected results using both FPXRF and laboratory methods were included in the plotted dataset for each metal. For the FPXRF measurements, detected sample results were considered those for which the mean XRF value included two or fewer non-detect quadrant measurements. Scatter plots for arsenic, barium, copper, iron, lead, manganese, nickel, selenium and zinc are presented in Attachment E-1. Linear, logarithmic, exponential, and power trend lines were fit to the plotted sample results and a least squares fit (i.e., R^2 value) for each trend line type was derived. The best fit line for each metal is provided in Attachment E-1 along with the corresponding trend line equation and R^2 value associated with the trend line.

With the exception of copper, the data plots illustrate only poor to moderate correlation between the mean FPXRF measurements and associated laboratory results for the VLT materials samples. For arsenic, barium, iron, lead, manganese, nickel, selenium, and zinc, the R^2 values associated with the best-fit trend line for each metal range from 0.02 to 0.77 (i.e., 2 to 77 percent correlation) and considerable data scatter is evident. For zinc in particular, the plot is skewed by what appears to be a single anomalous laboratory result of 1,800 mg/kg, which corresponds to an XRF measurement of 19 ppm (mg/kg). All of the remaining laboratory results for zinc are two orders of magnitude lower (i.e., less than or equal to 76 mg/kg). However, even if the data point corresponding to the 1800 mg/kg laboratory result is removed, substantial data scatter remains and the correlation remains poor. A "reasonably good" correlation coefficient of 84 percent was obtained for copper, and the sample data cluster more closely around the linear regression line. Although copper could serve as a potential metal for field screening purposes, its 84 percent correlation coefficient is not considered to be statistically reliable.

Boxplots

For the metals analyzed using FPXRF and laboratory methods, a series of boxplots were generated to compare metal-specific concentrations reported by each analytical method (Attached E-2). Summary statistics associated with the boxplots representing XRF and laboratory data are presented in Table 3 below. Boxplots are used as visual tools which summarize information about the shape, spread, and center of a dataset. The lower edge of the box represents the 25th percentile (1st quartile, Q1) while the top edge represents the 75th percentile (3rd quartile, Q3). The box portion of the plot is called the inner quartile range ($IQR = Q3 - Q1$) and contains 50 percent of the data observations. The vertical lines extending above and below the box are called whiskers. The whiskers extend out to the highest and lowest data observations that are not considered outliers. The range of values extending from the bottom of the lower whisker to the top of the upper whisker is considered to be the natural range of the data set. Outliers, represented by an asterisk, are defined as data observations which lie outside the box by a distance greater than 1.5 times the IQR (i.e. less than $Q1 - 1.5*IQR$ or greater than $Q3 + 1.5*IQR$). Outliers are generally considered to be non-representative of a given dataset.

Together, the inner quartile range (box) and the whiskers can be used to assess the symmetry of a data set. A data set whose median is centered within the IQR and which has whiskers of equal length is symmetric, meaning the data extend a similar distance both above and below the median. Conversely, a data set whose median is not centered within the IQR and which has whiskers of unequal length is asymmetric. An asymmetric boxplot indicates a data set where data extend further from the median in

one direction compared to the other. This is often the case when a data set is limited by some physical upper or lower bound. For example, in the case of chemical concentrations, a given data set would be physically bounded below by zero (or by the detection limit). Such a data set would likely produce an asymmetric boxplot which exhibits more spread in the data above the median than below (i.e. the median is located closer to the bottom of the IQR than to the top, and the upper whisker is longer than the lower whisker). This occurs because the data must all be at or above zero (or the detection limit) but are effectively unbounded from above, provided that the data are well below any physical upper bound such as a solubility limit or sorption capacity.

The comparison of boxplots from laboratory analytical results with boxplots compiled from field measurements using the FPXRF instrument would only be valid for circumstances where each dataset exhibits a reasonable frequency of detection. As noted previously, when a non-detect result was reported, the detection limit was substituted in place of an actual concentration value. The presence of numerous non-detects in a dataset will tend to confine the boxplot to a narrow region around the value of the detection limit and invalidate any visual comparison of data. With the exception of zinc, the primary conclusion that can be drawn from examination of the boxplots in Attachment E-2 and the summary statistics is that XRF measurements are generally higher than the corresponding analytical results reported by the laboratory for the VLT samples. The boxplots indicate that this relationship is consistent for metals that include a large percentage of non-detect results.

For copper, the only metal that indicates a potential correlation between XRF and lab data, the XRF measurements for the VLT materials are generally higher than the lab results and they encompass a wider range of values relative to the lab results. However, the two data sets do exhibit similarities with respect to their shape and spread. In each data set, the median value is approximately centered within the inner quartile range (box). This indicates that the inner 50 percent of the data are spread fairly evenly about the median value for both sets of data. Both boxplots exhibit a longer upper whisker and shorter lower whisker, which likely reflects the fact that the data are limited below by a concentration of zero but are well below a physical upper bound concentration. Each boxplot has a single outlier in excess of the natural range. In both cases, this outlier corresponds to sample VLT-XRF-18A. Given the similarities in shape and spread of the boxplots and the direct correlation of the outliers, it is probable that the XRF measurements and lab results are accurately capturing the underlying variability of copper concentrations in the VLT material. While the XRF measurements tend to over-estimate actual copper concentrations represented by the laboratory analytical results, this over-estimate is consistent.

This consistent relationship is illustrated on the bar chart shown on Figure 7, which plots the XRF measurements and laboratory analytical results in order from lowest to highest concentration based on the XRF measurement data set, excluding only the highest XRF/laboratory sample result identified in the boxplot as an outlier. A linear regression line was then fit to both data sets. Although the slopes of the two linear regression lines are slightly different, the regression lines indicate that the average percent difference between the XRF measurements and the laboratory results remains constant throughout the range of observed concentrations.

At the lower end of the bar chart, the FPXRF regression line intersections the concentration axis at a value of about 750 mg/kg, while the lower end of the laboratory results regression line intersects the concentration axis at a value of about 565 mg/kg. The difference between these two values is 185 mg/kg, which represents approximately 25 percent of the 750 mg/kg XRF regression line lower intercept. At the upper end of the chart, the XRF regression line intersects the concentration axis at a value of about 1865 mg/kg while the laboratory result regression line intersects the axis at a value of about 1400 mg/kg. Although the numeric difference between these two values is 465 mg/kg, this value also represents about 25 percent of the 1865 mg/kg XRF regression line upper intercept. Therefore, while the numerical difference between the FPXRF and laboratory results upper and lower intercepts are significantly different, they represent an essentially equal relative percentage difference between the two data sets. For copper, this indicates that: 1) FPXRF measurements will consistently over-estimate the corresponding laboratory result; and 2) the percentage difference of the over-estimate remains consistent over the range of concentrations observed from the sampled VLT materials.

| Table 3. Boxplot Summary for XRF and Laboratory Data | | | | | | | | | | | | | | | |
|---|--------------|-------------|------------|-----------|---------------|-----------|------------|--------------------------------------|--------------|-------------|------------|-----------|---------------|-----------|------------|
| XRF Measurement Data | | | | | | | | Laboratory Analytical Results | | | | | | | |
| Analyte | Count | Mean | Min | Q1 | Median | Q3 | Max | Analyte | Count | Mean | Min | Q1 | Median | Q3 | Max |
| | | | | | | | | Aluminum | 49 | 7724.49 | 3300 | 6250 | 7100 | 8100 | 16000 |
| Antimony | 49 | 54.08 | 50.25 | 53 | 54 | 55 | 58 | Antimony | 49 | 1.97 | 0.74 | 0.845 | 1.6 | 2 | 12 |
| Arsenic | 49 | 7.50 | 4.5 | 6 | 6.75 | 8.75 | 14.75 | Arsenic | 49 | 6.42 | 2.7 | 5 | 5.9 | 7.5 | 17 |
| Barium | 49 | 297.65 | 212.75 | 257.125 | 299 | 326.625 | 408.25 | Barium | 49 | 59.88 | 30 | 51 | 57 | 64 | 140 |
| | | | | | | | | Beryllium | 49 | 0.25 | 0.25 | 0.25 | 0.25 | 0.25 | 0.33 |
| | | | | | | | | Boron | 49 | 2.15 | 2.1 | 2.1 | 2.1 | 2.1 | 4.5 |
| Cadmium | 49 | 30.06 | 28 | 29.25 | 30 | 30.75 | 33 | Cadmium | 49 | 0.25 | 0.25 | 0.25 | 0.25 | 0.25 | 0.25 |
| | | | | | | | | Calcium | 49 | 3244.90 | 1300 | 2600 | 3200 | 3600 | 6700 |
| Chromium | 49 | 79.64 | 69.5 | 75.625 | 79.25 | 82.25 | 101.25 | Chromium | 49 | 23.08 | 11 | 18 | 23 | 27.5 | 40 |
| Cobalt | 49 | 10.66 | 8.25 | 10 | 10.5 | 11.625 | 13.75 | Cobalt | 49 | 3.88 | 2.1 | 3 | 3.5 | 4.2 | 9.6 |
| Copper | 49 | 1333.91 | 732.5 | 1052.125 | 1284.25 | 1560.875 | 2437 | Copper | 49 | 996.53 | 530 | 765 | 940 | 1100 | 1700 |
| Iron | 49 | 18996.42 | 12621.5 | 16693 | 18244 | 21946.25 | 30354 | Iron | 49 | 11955.10 | 7000 | 9750 | 11000 | 15000 | 19000 |
| Lead | 49 | 8.06 | 6 | 7 | 7.75 | 8.75 | 12.25 | Lead | 49 | 3.30 | 2.1 | 2.8 | 3.2 | 3.5 | 5.7 |
| | | | | | | | | Magnesium | 49 | 6136.73 | 2500 | 5050 | 6000 | 6900 | 12000 |
| Manganese | 49 | 62.38 | 51.75 | 58.375 | 60.75 | 65.75 | 92.75 | Manganese | 49 | 46.33 | 26 | 40 | 46 | 52 | 75 |
| Mercury | 49 | 7.33 | 7 | 7 | 7.25 | 7.5 | 8.25 | Mercury | 49 | 0.24 | 0.044 | 0.125 | 0.18 | 0.265 | 0.93 |
| Molybdenum | 49 | 15.57 | 14 | 15 | 15.25 | 16.25 | 18 | Molybdenum | 49 | 3.31 | 1.2 | 2.6 | 3.4 | 3.85 | 5.5 |
| Nickel | 49 | 34.55 | 27 | 31.125 | 34 | 37.125 | 51.25 | Nickel | 49 | 9.00 | 5.5 | 7.6 | 8.4 | 9.55 | 25 |
| | | | | | | | | Potassium | 49 | 1239.39 | 440 | 815 | 1100 | 1500 | 4200 |
| Selenium | 49 | 4.44 | 2 | 3 | 4 | 5 | 15 | Selenium | 49 | 3.28 | 1.4 | 2.5 | 3.1 | 3.7 | 9.1 |
| Silver | 49 | 29.31 | 26.75 | 28.25 | 29 | 29.75 | 36.25 | Silver | 49 | 0.25 | 0.25 | 0.25 | 0.25 | 0.25 | 0.27 |
| | | | | | | | | Sodium | 49 | 142.86 | 48 | 110 | 140 | 155 | 380 |
| | | | | | | | | Thallium | 49 | 0.58 | 0.49 | 0.495 | 0.5 | 0.5 | 1.6 |
| Titanium | 49 | 2196.73 | 1562 | 1841.75 | 2159 | 2558.25 | 2997.25 | | | | | | | | |
| | | | | | | | | Vanadium | 49 | 23.29 | 12 | 18 | 22 | 26.5 | 55 |
| Zinc | 49 | 16.41 | 12 | 14.5 | 16 | 18.25 | 23.5 | Zinc | 49 | 53.06 | 12 | 12 | 12 | 13 | 1800 |

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