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Pre and Post Blast Chemical Comparison of the Intra- and Inter-Variability of Metal Pipes Commonly Used in Pipe Bombs

Mandi Hellested

Thesis Submitted to the
Eberly College of Arts and Sciences
at West Virginia University
in partial fulfillment of the requirements
for the degree of

Master of Science
in
Forensic and Investigative Science

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ABSTRACT

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Mandi Hellested

Pipe bombs are a substantial problem around the world killing and injuring thousands each year. Traditionally explosive used, residues of explosives, and bomb components have been the main source of evidence in the investigation of a located or exploded pipe bomb. This research analyzed the trace elemental compositions of metal pipes to investigate if pipes can be compared. It was found that in a sample set of 37 pipes, of different brands and purchase locations, each pipe was homogenous at trace elemental concentrations. This homogeneity allowed for comparison between pipes. An x-ray tube, as an alternate excitation source, which had been added to a traditional scanning electron microscope – energy dispersive x-ray spectrometry system was used in this research. X-ray excitation versus the electron excitation of traditional SEM was able to detect trace elements in the pipe metal. The method was able to discriminate between 80% of the total sample set by trace elemental analysis comparison.

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Introduction

According data collected by the Federal Bureau of Investigation, between the years 1988 and 1997 there were a total of 13,654 actual explosive bombings and 3,728 attempted explosive bombings in the United States (1). Karmy-Jones et al. (2) reviewed data from 1980 to 1990 and found that of 12,216 bombing incidents the majority (53%) of the devices were pipe bombs. More recent data shows that bombings are still very much a source of concern for law enforcement. According to the U.S. Bomb Data Center, organized by the ATF, between 2004 and 2006 there were 10,957 explosive incidents, with 546 injuries, and 68 fatalities (3). Pipe bombs are by no means at all an issue just for the United States, they are a global problem. The National Counterterrorism Center's 2010 Report on Terrorism states that bombings were the most lethal of all terrorist attacks globally (4). In 2010 there were 4,275 bombings that resulted in 6,595 fatalities (4).

A pipe bomb is a sub-set within improvised explosive devices (IED). Thurman defines an IED as "a combination of items or components that are neither designed nor produced to be used in conjunction with each other and that, when placed together or assembled, constitute a mechanism that has the capability of exploding and causing personal injuries and property damage" (5). The basic components that make up an IED are: initiator, container, electrical components, timing mechanisms, shrapnel, adhesives, fasteners/wire and the explosive (5). The initiator is used to start the detonation; this can be fuses or electric matches. The container, though not used in all IEDs, is used in most for: containing the explosives, concealing the IED, transportation of the IED, or any combination thereof. For IEDs using low explosives, pipes and tubes are the most commonly used containers(5). For IEDs with electrical initiators, electrical components are required. This could include wire, batteries, switches or soldering of wires. According to Thurman, the most common way that IEDs are initiated is by time delay, giving the perpetrator time to place the device and leave before detonation (5). The timing mechanism can either be a mechanically or electrically controlled timer. Mechanical timers are generally windup clocks and watches, while electric timers are battery operated or run by household power. Shrapnel is anything that is added to the IED that is meant to increase its potential to cause

injury. This can include nuts, bolts, washers, nails, glass, metal and so on (5). Shrapnel can be put within the container or secured to the outside of the bomb. Adhesives are used to secure the components of the bomb together and prevent accidental dislodge, while fasteners are used in the construction of the bomb (5).

Explosives are chemical mixtures or compounds that react chemically to produce gas, light, and heat. They are most often solid or liquids that are able to rapidly produce a chemical reaction (5). A mixture is two or more chemicals that are merely physically mixed and retain their own properties, while a chemical compound is formed by two or more elements that are combined chemically to form a new substance. From a chemical standpoint, an explosive requires two things to propagate combustion: a fuel to burn and an oxidizer to support the combustion, though it may contain other ingredients. An oxidizer is required due to the fact that the combustion of explosion is so fast that surrounding air cannot feed the reaction with enough oxygen (5).

Explosive materials can react either via deflagration or detonation. Deflagration is a very rapid burning, and expansion of gas, however no pressure wave is formed. Detonation is also a rapid burn, but with more power and pressure that produces a pressure wave. When under pressure, due to containment, deflagration can be forced to detonation. Low explosives are deflagrating explosives that only detonate when confined (6). Confinement, which contains the building pressure of combustion, allows the compression wave produced by the rapid burn of the low explosive to accelerate to become a detonation wave (6). Low explosives burn faster and with more power than when confined than in open air, but still slower and less explosively than high explosives. High explosives can detonate regardless of confinement, however when confined, the speed of reaction increases and can cause greater damage than when unconfined. Pipe bombs most commonly use low explosives (5).

Low explosives are commercially available as propellants, including black and smokeless powders, photo flash powder and Pyrodex®. With pipe bombs, the container is a generally a metal pipe with some sort of end cap to hold the explosive and other components in and provide the confined, pressure building, conditions needed for an explosion using a low explosive. The ‘classical’ pipe bomb is a steel pipe with threaded end caps (7).

When processing a bombing scene the search for fragments of the device is a priority. The end goal is to recover evidence that can be used to identify a perpetrator. Law enforcement faces a large challenge recovering evidence from a bombing scene. Damage and debris from the explosion can make identification of portions of the bomb difficult. Also, bombs are often on a time delay and the perpetrator leaves behind little physical evidence, making it difficult to identify possible suspects or to link individuals to the device (8). In other types of crimes, the perpetrator is physically present during the commission of that crime. This increases the probability of evidence being left behind. According to Locard's Exchange Principle, the intensity of committing a criminal act leaves behind evidence of that act. For example in a physical assault, there is contact between the perpetrator and the victim. This contact can leave trace evidence such as fibers or hair transferred between both the victim and the perpetrator; fingerprints and DNA can be left behind, as well as eye witnesses. However, with a time delayed bomb, there is no intense activity associated with the setting of the device, thus lessening the chances of trace evidence. The perpetrator can set a concealed bomb and be out of the area hours before it detonates, and evidence left on the bomb itself can be lost or destroyed by the detonation.

All remnants of an exploded IED that are collected are processed as evidence. The discovery of fingerprints or DNA on shrapnel is likely to be the most valuable evidence recovered since it can link a suspect directly to the device. These types of evidence are not commonly found post blast due to the high heat of the explosion which destroys such evidence (8). Residues can be analyzed to determine the types of explosive used in the device. The type of explosive used can possibly be traced back to suppliers in the surrounding area of the bomb, and then further linked to a suspect from purchase records. Black powder substitutes are commonly used in IEDs. These materials have started to replace traditional black powder in commercial retail stores due to less restrictive storage requirements (9).

Routon et al. evaluated the ability to discriminate between the two most common black powder substitutes using Gas Chromatography – Mass Spectrometry (GS-MS) (10). Pyrodex and Triple Seven are similar to black powder but are more stable for storage and transportation(11), (12). Black powder is classified by the Department of Transportation as a Class 1.1 explosive, meaning it has a mass explosion hazard (13), (14). While Pyrodex and Triple Seven are

considered Class 1.3 explosives which have a minor blast or fire hazard, but not a mass explosion hazard (14). Pyrodex and Triple Seven powders are similar in physical characteristics and their particles cannot be distinguished visually, but they can be differentiated chemically(10). Pyrodex contains sulfur, sodium benzoate, and dicyandiamide. Triple Seven does not contain sulfur, but contains 3-nitrobenzoic acid.

Other researchers analyzed black powder substitutes containing ascorbic acid via Ion Chromatography – Mass Spectrometry (IC/MS) (9). Ascorbic acid is used as a fuel in this group of low explosive black powder substitutes. Ascorbic acid containing powders are becoming more prevalent bombings (9). Ascorbic acid degrades quickly making identification of the black powder substitutes challenging. Their method showed promise which warrants further research.

Kosanke et al. analyzed explosive residues via particle analysis in a Scanning Electron Microscope with Energy Dispersive Spectroscopy detection (SEM/EDX) (15). This study indicated that this technique could discriminate between pyrotechnic residues and unrelated background contamination. It is difficult to distinguish in a bulk chemical analysis of post blast material between residue from the blast and other materials which may have been deposited on the scene by other means. Possible background contamination can come from the soil, weed killer or fertilizer. Using an SEM allows to attribute particles to the blast due to their morphology and size.

Gregory et al. studied the structural changes of pipe bomb fragments caused by various strengths of explosives (16). The strength of an explosive is defined by the amount of heat and volume of gas it produces (6). The explosive index compares the relative power of explosives. This group exploded pipes under controlled conditions and analyzed the fragments using SEM, optical microscopy and microhardness. They were able to correlate the microstructural changes with the relative energy of the smokeless powder used. It was found that higher power propellants resulted in more plastic deformation, or change in shape of the metal, than that of lower powered propellants. Also, higher power propellants produced more work hardening, or strengthening, in the metals as indicated by an increase in microhardness.

Oxley et al. studied the distribution of fragments of pipe bombs, which were detonated under controlled conditions (17). It was found that the number, size and appearance of the

exploded pipe fragments were correlated to the explosive power of the device. The more powerful explosives produced more and smaller sized pieces than the lower powered explosives. More specifically, for seamless pipes, a high energy explosive destroyed the end caps and tore the pipe into wide strips. While the same energy explosive tore a seamed pipe into thin strips and broke the end caps into a few pieces. Also it was found that very low energy explosives such as black powder tore apart the pipe at its weakest point, which is usually where the pipe and cap meet.

Given the above, current research has focused on the identification of the explosive material used in the device (16), (17). Little, if any, research has been performed on the chemical composition of materials typically used in pipe bombs and its relation to source attribution. However, there has been research on using trace elemental composition of materials for source attribution purposes. It has been shown that very similar samples can be differentiated when comparing relative concentrations of trace elements.

Watling et al. characterized the trace element composition of native gold from three Australian mines using Laser Ablation Inductively Coupled Plasma-Mass Spectrometry (LA-ICP-MS). This analysis allowed for the creation of a trace element signature or a chemical fingerprint of the samples (18). This research arose due to increased gold theft in Australia, and the need to identify gold which had been melted down. This method was investigated due to the ability of LA-ICP-MS to detect elements at very low levels directly from a solid sample. Watling was able to effectively differentiate three samples of gold from three different mines with different matrices. Due to the samples having different matrices the laser would not couple in the same way to each sample and thus different amounts of material were ablated. These differing amounts would make quantitative comparison impossible. In their study, being able to differentiate between the three different mine samples was a result of each sample having noticeably different combinations of trace elements as well as different relative concentrations. Actual, quantifiable concentrations were of no value in the differentiation between the samples. These findings support the hypothesis that steels can be differentiated in a similar manner since the material in each steel sample originates from various natural mine sources. It is this natural origination that would impart different chemical compositions and concentrations into the ores which make up the steel.

Later work of Watling and colleagues indicated that it was possible to differentiate between samples of steel using LA-ICP-MS (19). They were able to indicate that a comparison of the inter-element association patterns was distinct enough to differentiate between different glasses and steels from similar objects.

The optimized conditions for LA for the glass and steel samples were quite different. For the glass samples the laser was run in a switched pulse mode, which is better for non-conductive samples. This mode generates ionizing plasma above the sample which then erodes into the sample by vaporizing it. For the steel samples the laser was run in a fixed pulse mode. The energy of the laser is absorbed by the sample causing it to liquefy and then to form an aerosol. The instrument was optimized using a glass standard from NIST. No steel standard was run since continuous ablation of a metal coats the inside of the laser which results in contamination.

For the optimization of the laser for use with glass, voltages from 550V to 850V in 100 volt increments with repetition of laser shots of 5, 10, and 15 hertz for periods of 30, 60, or 90 seconds were used. It was found that the optimum setting for glass was 750 volts at 15 hertz for 60 seconds.

Similar optimization for steel resulted in using 800 volts with one or two shots gave the most reproducible ablation. Higher energies caused the metal that had become molten to erupt and disperse over too large of an area. It was found that two laser shots per site was optimal due to the first shot heating up the cold metal and the second produced molten metal.

It was possible to differentiate between five different colorless glass samples that had refractive indexes that differed by less than 0.1%. These samples were tested ten different times over a two month period, and indicated very good repeatability of the data.

Their steel sample set included steels from safes, firearm barrels, tools, angle iron, rods, and crowbars. This method was found to be repeatable for steel. It was also possible to differentiate five different safes on three different runs over a three month period.

Watling et al. used ternary plots to compare different trace element ratios of seven different steel samples. Using the various combinations of elements, the relative position of each datum would indicate the similarity of samples. Considering the precision of the method, the

closer the data were, the more likely they would originate from the same sample. By plotting the same samples using a different combination of trace elements, the differences between samples were easily resolved. The various trace element combinations resulted in varying degrees of differentiation. They also were able to differentiate samples from similar sources when comparing steel from five different safes by using various combinations of trace elements.

The results of Watling's study suggests that it is possible to differentiate between metal pipes using LA-ICP-MS. Commercially available pipes, which are commonly used in pipe bombs, are black iron pipes which are furnace-welded (20). Generally, the properties of pipes are controlled by standards set by the American Society for Testing and Materials (ASTM). The standard for black iron pipes (ASTM A53/A53M) establishes requirements for the chemical compositions of these pipes and also sets maximum allowable amounts for specific elements. ASTM A53/A53M requires furnace-welded black pipes to have a maximum of the following elements (21):

Carbon	Manganese	Phosphorus	Sulfur	Copper	Nickel	Chromium	Molybdenum	Vanadium
0.03%	1.20%	0.05%	0.045%	0.40%	0.40%	0.40%	0.15%	0.08%

Table 1. ASTM maximum chemical composition for furnace-welded pipe

It is possible for a pipe to contain these elements in lesser amounts. Other elements may be present since they are not controlled under the standard. Considering the standard, it is expected that analysis of these pipes would indicate the presence of the above elements at some level. Since the pipes are steel, it is expected that the main components will be present in about the similar ratios from pipe to pipe. The expected concentrations of elements in steel pipes are mostly iron, with carbon (0.5%-1.7%), and manganese (1.67%) (22). Small amounts of silicon, aluminum, sulfur, oxygen and nitrogen are also expected to be present, as well as chromium and cobalt. It is these lesser present elements that will be used for comparison. Carbon will not be considered as a comparative element, as it is purposefully added to iron to form the alloy that is steel, in order to strengthen and increase the hardness of the steel.

As Watling found with gold (18), mined materials are imparted with trace levels of elements depending on their origin. Steel that is used to make pipes originate as iron ore. Iron ore is mined all over the world, with China as the primary producer in 2004, with Brazil and Canada

second, followed by India, Russia, and Ukraine (23). The United States was the sixth largest miner of iron ore in 2004 (23). These data show the wide variety of regions producing iron ore which supports the hypothesis that steel pipes can be differentiated as a result of their different origins and trace element compositions. This differentiation of steels has been shown in other materials (19), but not yet with steel pipes.

In the report by the National Research Council on bullet lead evidence, extensive research was done to evaluate the value of the chemical comparison of bullet lead evidence (24). Forensic scientists have compared bullet fragments from a victim to unused cartridges from a suspect. The report found that although the lead in bullets may not be traceable to their origin due to variability in the manufacturing process, there is still value in chemical comparison. The report stated that “bullets from the same compositionally indistinguishable volume of lead (CIVL) are more likely to be analytically indistinguishable than bullets from different CIVLs”. This chemical analysis can provide a probability that two bullets came from the same volume of lead. The conclusion of this National Research Council report gives further purpose to this research. The aim of analyzing shrapnel from pipe bombs is not to determine the origin of the metal, but to link it back to cuttings or shavings which are associated to a suspect or a site. If the analysis of steel indicates distinguishable differences in the pipes, it may be translated to real forensic investigations, and thus add weight to the probability of steels coming from the same source, or equally as important, from different sources.

The focus of this research was to analyze metal pipe types that are commonly used in pipe bombs through the intra- and inter- variability of the chemical composition of the pipes. First, the research evaluated if each pipe was chemically homogenous throughout the pipe from end to end as well as across the face of each cross section. Secondly, the variability between the pipes was evaluated. This research was done with the aim of finding another tool of evidence analysis in pipe bombings. The chemical composition of shrapnel from a bombing scene may be compared to metal cuttings or shavings found at the location where the bomb was suspected to be made, and either linked or excluded by similar trace element ratios.

Cross sections within one pipe were compared to each other, as well as cross sections between pipes of the same brand from the same retail location. Pipes of the same brand were compared between different retail locations. The purpose of the pipe analysis is to determine if

pipes can be differentiated by trace elements possibly between brands or batches of pipe, or at best between individual pipes.

The samples were first analyzed using a Laser Ablation Inductively Coupled Plasma-Mass Spectrometry (LA- ICP-MS). Laser Ablation ICP-MS was selected for its ability to produce trace element signatures or fingerprints of metals (19). A regular ICP-MS, without laser ablation, requires that metal samples first be dissolved prior to analysis. While LA-ICP-MS uses a laser for initial sample volatilization prior to analysis, eliminating the need for sample dissolution. A LA-ICP-MS uses a laser to volatilize the solid sample before it is introduced as an aerosol into the plasma via an argon gas carrier. The plasma is an electrically conductive gas containing charged particles. When atoms of a gas are excited to high energy levels the atoms lose hold of some of their electrons and become ionized, hence producing plasma with electrically charged particles. The ICP produces temperatures of about 8000°C, which generates ions from the aerosol and then introduces these ions into the Mass Spectrometer (MS). The MS then separates the ions according to their mass-charge ratios identifying the elements. The results from the LA-ICP-MS of what trace elements are in the pipe samples will be used to guide what elements are analyzed using the Scanning Electron Microscope/Energy Dispersive X-ray Spectroscopy (SEM/EDX), due to the LA-ICP-MS having a much lower detection limit than SEM/EDX. If an element is at such low concentrations that it not detected in LA-ICP-MS analyses it will most certainly not be detected with SEM/EDX analyses.

Further comparison was done using a Scanning Electron Microscope/Energy Dispersive X-ray Spectroscopy with an addition of an X-ray tube. The X-ray tube addition was used as an alternate excitation source in attempts to detect elements at or below the limit of detection with electron excitation alone. The scanning electron microscope works by scanning a focused beam of electrons onto a solid sample and interacts with the surface. The electron beam is produced by applying a voltage across a tungsten filament. The anode plate located below the filament forms powerful attractive forces for the electrons, drawing them towards the plate. Some of these electrons accelerate past the anode down the column to the sample. The electrons interact with the sample producing measurable electron energies, secondary electrons and backscattered electrons, which are analyzed to produce a three-dimensional image of the surface of the sample. Both the electrons of the electron beam and X-rays interact with the electrons in the shells

surrounding the nucleus. Characteristic X-rays result when the beam of electrons or X-rays eject inner shell electrons of the atom. The space left in the shell by the ejected electron is subsequently filled by an electron from an outer electron shell, and thus the extra energy from this transition is emitted as a characteristic X-ray.

While the Energy Dispersive X-ray detector or EDX (also referred to as EDS) analyzes the samples' atomic composition by measuring the element specific energies of characteristic X-ray. The primary excitation source for this research is an X-ray tube to analyze elements that would otherwise not be seen with electron excitation alone due to the higher energy of the X-rays versus the electron beam. The higher energy of the X-rays is strong enough to react with heavier elements and at lower concentrations. Being able to detect elements at lower concentrations can potentially increase the number of trace elements detected within the sample, thus increasing the number of inter-element combinations possible, in so doing increasing the probability of providing a useful chemical fingerprint for comparison (18).

Little or no sample is actually consumed or destroyed during an analysis using either LA-ICP-MS or SEM/EDX/X-ray. This property makes either method a perfect fit for forensic applications since the sample is not destroyed and thus can be retained for further testing.

To assure that a method is able to produce reliable data, the accuracy, precision, and repeatability of the method must be assessed. Accuracy is a measure of the closeness of a test result to an accepted reference value. This can be achieved by comparing the results of the analysis of a certified reference material to those values in the certificate of analysis (COA). Precision is a measure of the closeness or spread of measured values for a particular measurand. An estimation of precision can be obtained by evaluating the spread of data after repeat analysis of a particular measurement. This was achieved by evaluating the results from five replicate analyses of an iron standard. It is possible to use standard deviation as a measure of spread. This however, requires a relatively large sample set. Since a relatively small sample set is used, a t-distribution will provide for a better estimation of the spread. A confidence interval is a range which, when a new measurement is made, its value will fall within this range with a given probability (typically 95%) (6). Repeatability is a measure of how well a method will deliver the same result given the same instrument, operator, conditions, etc. over an extended period.

Limit of detection, or LOD, is typically defined as the level where no significant response can be detected. However for this method, LOD was defined as when the lower value of the confidence intervals is at or below zero.

Materials

Lowe's Home Improvement and Home Depot are the two major hardware stores in the United States. Lowes has over 1,745 stores in the United States, Canada and Mexico, while Home Depot has about 2,239 stores in the U.S, Canada and Mexico (25), (26). Kessler Industries, LDR Industries, and Mueller Brands are the three distributors that stock the shelves with pipes for Lowes and Home Depot across the country. Though Ace Hardware is not as numerous or widespread as Lowe's or Home Depot, they still recommend to their franchise owners to buy Mueller. From the variety of Lowe's and Home Depot stores contacted from across the country, the vast majority of the pipes carried were Mueller. Due to the availability of these brands across the country, they can be considered to be common pipes, and hence a good sampling population from which pipe bomb makers might choose their pipes.

Though the exact manufacturer of the three major pipe brands' steel is considered proprietary information, calls to the pipe manufacturer revealed that LDR uses steel made in China and Mueller uses steel made in Mexico (27), (28). The manufacturer of Kessler's pipe steel could not be determined. LDR and Mueller using steel from such distant and different locations adds to the possibility of being able to, at the least, differentiate between brands. Steel is made from mined iron ore. Iron ore, limestone and coke are combined and heated to temperatures over 3000°F until it reaches a molten state producing iron (29). The molten iron is either treated in a basic oxygen furnace or an electric arc furnace with scrap, converting the iron into steel (29). Welded pipes are made by pouring the molten steel onto a rolling caster and then rolled into pipes while hot, and then are welded at the seams. It is this melting, and pouring that leads to the hypothesis that the metal will most likely be chemically homogenous throughout.

Iron ore can be of different types depending on location of origin (30). This difference in origin, and hence type, could possibly be reflected in trace levels of impurities, allowing for differentiation between brands.

Sampling

Commercially available black iron pipes were purchased from a variety of hardware stores in Pennsylvania, Ohio and West Virginia. A total of thirteen stores, in six different cities, were collected. At each location, if available, the same size and brand of pipe was bought in triplicate. All of the pipes are one inch in diameter, with the majority having lengths of eight inches. Refer to Table 2 for the full sample matrix.

Location	Store Name	Brand	Sample ID
Massillon, OH	Menards	LDR China	1-1, 1-2, 1-3
Massillon, OH	Lowe's	LDR China	2-1, 2-2, 2-3
Washington, PA	Home Depot	LDR China	3-1, 3-2, 3-3
Washington, PA	Lowes	Mueller Proline	4-1, 4-2, 4-3
Robinson, PA	Home Depot	Mueller B&K	5-1, 5-2, 5-3
Robinson, PA	Lowe's	Mueller Proline	6-1, 6-2, 6-3
Wheeling, WV	Lowe's	Mueller Proline	7-1, 7-2, 7-3
Wheeling, WV	Northern Panhandle Pipe and Supply	Wheaton	8-1
Wheeling, WV	Northern Panhandle Pipe and Supply	China Brand unknown	8-2
Wheeling, WV	Northern Panhandle Pipe and Supply	Ukraine Brand unknown	8-3
Morgantown, WV	Lowe's	Mueller Proline	9-1, 9-2, 9-3
Morgantown, WV	Ace Hardware	Wheatland	10-1
Morgantown, WV	Ace Hardware	Anvil Corp	10-2, 10-3
Cleveland, OH	Home Depot	Mueller B&K	11-1, 11-2, 11-3
Cleveland, OH	Lowe's	Mueller Proline	12-1, 12-2, 12-3
Washington, PA	McKean Plumbing and Heating	Wheaton	13-1, 13-2, 13-3

Table 2. Samples highlighted in gray denote samples sent for LA-ICP-MS testing.

Northern Panhandle Pipe and Supply did not have multiples of pipes like the larger stores; however they did have more of a variety of pipes. The portions they provided were remainders from larger pipes, and hence were not purchased in triplicate. Ace Hardware in Morgantown only had one long pipe from Wheatland that fit the diameter specifications of one inch. Only one portion of this pipe was bought due to the fact any others would be known to be from the same pipe. Also, Ace Hardware only had two of the Anvil Corp pipes, and hence three were not purchased.

Of the collected pipes, portions of five different brands were sent out for LA-ICP-MS to the Department of Geology at the University of Maryland in College Park, Maryland. These samples are highlighted in green on Table 2.

Sample preparation

All of the pipes were first cut in half using a liquid-cooled diamond saw, and then a slice was cut from the center. Refer to Figure 1.

Figure 1 Slice from the center of the pipe

Then a slice was cut from the end of the pipe near the threading.

Figure 2 Slice from the end of the pipe

Each slice had a portion cut out. Portions from the middle slice were purposely cut to be smaller than the portions from the end, to avoid confusion once the samples were mounted.

Figure 3 Middle portion

Figure 4 End Portion

Figure 5 Size Comparison

In naming the samples the end portion is referred to as A and the middle is referred to as B. For example the first pipe purchased from Menards in Ohio, is 1-1. The end slice from this pipe is 1-1-A, while the slice from the middle is 1-1-B.

All of the pipes were cut using a liquid-cooled diamond blade Buehler Ltd. Cutter 10-1030.

The portions of pipe were then mounted in Konductmet I (Buehler) using a Buehler SimpliMet 3000 Automatic Mounting Press. The press was run at 4200psi at 360°F for eight minutes, followed by a cool down period of five minutes. The portions were mounted in such a way that the cross-sections of the pipes' diameter was facing outward for analysis.

After mounting, the samples were polished eight at a time using a Buehler Euromet I/Ecomet IV Polisher/Grinder. The samples were polished using successively finer grits starting at 120, 320, 600 and finally 1200 grit sandpaper, run at 35psi and 200rpm for 1.5 minutes. The samples were rinsed thoroughly between each grit level so as to remove residue that might scratch the metal during the next grit level. The samples were then polished one at a time by hand via the paper method using LECO Microid Diamond Compound, first using nine microns and then six microns. The samples were again rinsed between each grade to avoid scratching with a higher grade once moved to a lower grade. After the paper polishing method the samples were polished one at a time by hand on a Buehler Ecomet Variable Speed Grinder/Polisher at three microns using LECO Diamond Dosing stick. To minimize cross contamination between samples, the polishing wheel was cleaned between each sample with running water and scraping

against the entire wheel while running no less than four times, with rinsing of the scraper between each round of cleaning.

The samples to be sent for LA-ICP-MS, were only cut into the small portions of the slices as described above, and slightly polished to remove any burrs from the cutting process. The samples were rinsed well to eliminate any residue of the coolant used for cutting the metal. The researchers at the LA lab prepared the samples according to their needs.

Photographs of all machines used in the preparation of the samples can be found in Appendix 1.

Methods

LA-ICP-MS

The five samples highlighted in gray in Table 2. were analyzed using Laser Ablation Inductively Coupled Plasma Mass Spectrometry (LA- ICP-MS) at the University of Maryland's Geology Department. The instrument is a ThermoFinnigan Element 2 sector field mass ICP-MS. The samples were run in low and medium resolution modes. Low resolution provides data on higher mass elements, while medium resolution provides data on low mass elements. Ablation was carried out using a New Wave UP213 laser, which is a frequency quintupled NdYAG, giving 213nm UV light. The laser was fired at 7Hz with an energy fluence of $2\text{-}3\text{Jcm}^{-2}$. The laser was used to ablate lines perpendicular the edge of the pipe, across the diameter of the slice. The data was processed using LAMTRACE software. NIST standards were run before and after the samples in each of the modes. The standards used were a high nickel steel (SRM 1158) and steel containing chromium and vanadium (SRM 1263a)(31).

SEM/EDX/Xray

All of the samples, as well as copper and iron standards, were analyzed using a Jeol JSM-6490 LV Scanning Electron Microscope with an Oxford INCA X-sight Energy Dispersive X-ray Detector. Also an iXRF Systems Xbeam X-ray tube was used. The data was collected using Iridium Ultra software. All of the samples, copper standards, and iron standards were run with only X-ray excitation at 50kV at a working distance of 18mm. This energy produced about 500-700 counts per second, giving a total run time on average of 28 minutes for the samples run to a total of one million counts. Also, for comparison, the copper and iron standards, as well as the 5 samples analyzed on LA-ICP-MS were analyzed using the electron gun. The SEM was set at 20kV with a spot size of 53, at 500 times magnification and a working distance of 20mm. This energy produced about 3,000 counts per second, giving a total run time of about 7 minutes when running to one million counts.

Standards

Basic copper tape was used as a standard for system calibration. An iron sample containing multiple trace elements was also used. The iron sample (BS-41) is tool steel, certified by Brammer Standard Company, on loan from iXRF Systems. Table 3 shows the trace element values of standard BS-41 as per the Certificate of Analysis(32).

Mn	P	S	Si	Cu	Ni	Cr	Mo	W	V	Fe
0.89	0.013	0.011	1.02	0.038	0.15	0.22	0.23	0.035	0.05	97.343

Table 3. Element values from COA, values shown as weight percent

System Calibration

Copper was used daily as a system calibration check. The copper was run before the iron standard and any samples. The samples and iron standards were run for a total of one million counts, while the copper standards were run to thirty-five thousand counts. The samples and iron standards were collected at higher counts to allow for lower detection of lesser present elements. The copper standards were run to verify that the system was calibrated and that the correct peaks were being identified.

Control charts were calculated for the intensities of the copper peaks as well as the energies of the peaks. The charts show upper limits (UL) and lower limits (LL), using three times the standard deviation, as well as upper warning limits (UWL) and lower warning limits (LWL) using two times the standard deviation (6). In general, with control charts, should the upper or lower limit be breached, the system would be stopped and investigated for what is causing the out of limit reading. If the warning limits are crossed, the system is monitored, but allowed to continue collecting data. As seen in both charts below, there were no standards run that crossed the upper or lower limits.

Figure 6. Control Chart for Copper Standard Intensities

Figure 7. Control Chart for Copper Standard Energy

These charts are visual representations that the system is stable from day to day, is properly calibrated and hence is correctly identifying peaks.

Repeatability

To assess the repeatability of the method, five replicate analyses were taken of the iron standard, as well as daily analysis. The five replicate analyses were taken at five different points on the standard disk to also analyze the homogeneity of the disk while testing the method's reproducibility. Daily analyses exhibited the method's repeatability; 11 analyses were taken over 21 days. The averages and confidence intervals for the two sets of standard data were calculated and can be seen in Tables 4 and 5. The spread of the confidence intervals for the 5 replicate standards represents the precision of the analysis, while the spread of the confidence intervals for all of the standards represents the repeatable from day to day.

BS-41 5 Replicates (wt %)	Mn	P	S	Si	Cu	Ni	Cr	Mo	W	V	Fe
Average	0.89	0.00	0.01	0.10	0.01	0.07	0.16	0.02	0.05	0.08	98.61
95% Confidence Interval	0.86	0.00	0.00	0.09	0.01	0.06	0.14	0.00	0.04	0.07	98.56
	0.92	0.00	0.02	0.11	0.02	0.08	0.17	0.04	0.07	0.09	98.66

Table 4. Average and Confidence Intervals of 5 replicate BS-41 standards

All Standards (wt %)	Mn	P	S	Si	Cu	Ni	Cr	Mo	W	V	Fe
Average	0.90	0.00	0.01	0.09	0.01	0.07	0.16	0.02	0.06	0.08	98.61
95% Confidence Interval	0.88	0.00	0.00	0.08	0.01	0.07	0.15	0.01	0.05	0.07	98.58
	0.92	0.00	0.01	0.09	0.01	0.07	0.16	0.02	0.06	0.08	98.61

Table 5. Average and Confidence Intervals of all BS-41 Standards

Figure 8 below shows all of the BS-41 standards overlaid, and Figure 9 shows the same spectrum zoomed in to better exemplify the repeatability.

Figure 8. Overlay of all BS-41 standards

Figure 9. Close up of all BS-41 Standards

Limit of Detection

The limit of detection was estimated by reviewing the data for all of the sample analyses of individual full pipe comparisons. For example, when reviewing the full pipe data for the samples for Tin and Antimony the calculated lower confidence intervals are at or crossing zero, meaning these values are at or below the limit of detection. These elements were not considered for comparison. The full pipe analysis and related confidence intervals can be seen in Appendix 2.

Samples

All of the samples were analyzed at three separate locations across the slice. Slices from the end of the pipe were larger and referred to as “A”, while slices from the middle of the pipe were smaller and referred to as “B”. As seen in Figure 10, the slices were tested at the top, middle and bottom.

Figure 10. Test areas of samples

The five samples that were sent for LA-ICP-MS were more heavily focused on in terms of sampling. This was done to have a wider range and amount of data for five different brands of pipe. For each of these five samples, each sub sample or slice was consecutively run in duplicate at the same middle spot, as well as the three areas as described above.

Results

X-ray analysis versus SEM analysis

The copper and iron standards as well as the five samples run on LA-ICP-MS were analyzed using the electron beam of the SEM as well as X-rays. This was done to compare the two methods. The SEM analysis showed the broad peak caused by Bremsstrahlung, as well as a copper $K\alpha$ peak and a smaller copper $K\beta$ peak. Bremsstrahlung is caused by electrons interacting with the nucleus of the atom instead of the electrons, and losing energy in the interaction. Bremsstrahlung is an electron generated radiation, and hence it is not present when using X-rays as the excitation (33). The higher energy of the X-ray shows more $K\beta$, but less L lines than with SEM. The Copper concentration is the same for both analyses; however it is represented differently because of the energy it is being bombarded with. All of these observations can be seen in Figure 11 and 12 below.

Figure 11. Copper standard spectra analyzed using SEM at 20kV

Figure 12. Copper standard spectra analyzed using X-rays at 50kV

The BS-41 standard was also analyzed using both SEM and X-ray excitation. The standard is certified and hence has known concentrations of elements at low levels. It should be noted that the standard was certified using Inductively Coupled Plasma and Atomic Absorption spectrometry, wet chemistry and combustion instrument procedures (34). Certification testing did not include SEM or X-ray analysis. There may be slight differences in calculated elemental concentrations due to the differences in types of analysis. However the focus is to compare differences between SEM and X-ray recoveries as compared to the known values. The closeness of these measured values to the known values of the certified standard used exemplifies the accuracy of the method. This is shown in Table 6.

Elements	Mn	P	S	Si	Cu	Ni	Cr	Mo	W	V	Fe
Certified (wt %)	0.89	0.01	0.01	1.02	0.04	0.15	0.22	0.23	0.04	0.05	97.34
Xray	0.90	0.00	0.01	0.09	0.01	0.07	0.16	0.02	0.06	0.08	98.61
SEM	0.80	0.06	0.00	1.11	0.09	0.19	0.19	0.52	0.60	0.08	96.39

Table 6. Comparison of X-ray and SEM concentrations to BS-41 Standard

The differences shown above are not substantial, however it must be taken into consideration that the software (Iridium Ultra) was used to manually select the elements. Due to Bremsstrahlung with electron excitation the recoveries seen above can partially be attributed to

Bremsstrahlung being counted as characteristic X-rays, artificially raising the percentage. It is also possible that with SEM some of the elements that were calculated may not even be seen visually as actual peaks, but is only background being calculated as a peak.

Sample 1-1 was analyzed using both SEM and X-ray excitation. Figure 13 is a spectrum from the sample analyzed using SEM/EDX. In this spectrum the Bremsstrahlung can be clearly seen. This effect is not visible in Figure 15, where the spectrum was collected using the x-ray tube as the excitation source. These spectra clearly indicate the difference in interaction between x-rays and electrons with the sample.

Figure 13. Sample 1-1 analyzed using SEM

Figure 14. Sample 1-1 analyzed using X-rays, full spectrum

Figure 15. Sample 1-1 analyzed using X-rays, zoomed in on the spectrum

LA-ICP-MS Analysis of Samples

The five samples sent for LA-ICP-MS analysis were chosen for their differences in brand and origin anticipating a higher probability to be differentiated from each other. The LA-ICP-MS analyses searched the samples for a total of 25 elements. Refer to Appendix 3 for the entire set of LA-ICP-MS data. The data indicate the presence of elements at concentrations of less than one part per million. After preliminary experiments using SEM with X-rays, it was decided that only a sub-set of the elements identified by LA-ICP-MS would be used in this research due to the very low concentrations of the elements which were excluded. It was determined that if any element, in any of the samples, was present above ten parts per million it would be used in this research. After reviewing the results, it was found that 15 elements were present above the predetermined threshold of 10ppm. Refer to Appendix 4 for an abbreviated version of the LA-ICP-MS data that only includes the 15 selected elements, at 23 isotopes.

For the five pipe samples tested with LA-ICP-MS, a portion from the end and from the middle were analyzed as single analyses.

Some elements are present in both modes of analysis. The averages of each element present in each sample set, at all modes, were calculated. Due to the data showing that the middle and end portions of the pipe are compositionally the same, they were averaged together and are considered one sample for subsequent LA-ICP-MS data analysis. The averaged counts can be seen in Table 7. These values are used only as a bench mark for what elements to investigate with the SEM/EDX/X-ray analyses due to single analysis on the samples.

Sample	P	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Ga	Ge	As	Mo	Sn	Sb
1-1C	226	49	29	316	4041	937151	66	181	135	22	11.5	48	28	8.5	14
4-1C	279	84	32	438	4362	943310	36	166	59	16	8.6	29	6.6	71	4.0
8-3C	188	2376	7.4	488	4608	964980	46	423	544	9.8	18.2	89	45	39	16
10-2C	138	103.01	9.8	387	4475	926909	16	104	147	4.4	33	23	27	16	4.4
13-1C	188	68.88	6	298	3920	947301	19	154	183	4.7	34	31	59	71	8.1

Table 7. Averaged Elemental concentrations (ppm) from LA-ICP-MS Analysis

The table shows that there are differences between some of the elemental values. Similar to the ternary plots of Watling's work, two elements plotted against each other shows distribution of single analyses in Figures 16 and 17. More than one analysis would need to be

done using LA-ICP-MS to be able to use the data for comparison purposes; however the visual representation gives direction to the SEM/EDX/X-ray work. In the x-ray analyses multiple samples and repeat analyses were performed. The results of these multiple samplings will allow for some comparative interpretation of the LA-ICP-MS data.

Figure 16. Comparison of samples by titanium and vanadium

Figure 17. Comparison of samples by copper and tin

Continuing to combine different elements only further exemplifies the possibility of the value of comparative concentrations for differentiation. Refer to Appendix 5 for more comparisons.

X-ray Analysis of Samples

All of the samples were analyzed using X-rays as the excitation, and were tested across the pipe as shown in Figure 10. The five samples run on LA-ICP-MS were consecutively run in duplicate at the same middle spot to show repeatability of the measurements. Appendix 6 shows the elemental values for the duplicate analyses by weight percent. The very low standard deviation values show the values are repeatable.

All of the data was analyzed by reviewing the counts at the kV of the characteristic X-rays for the elements being reviewed. The pipes were compared first for intra-variability. The averages of the counts for the elements were compared for the middle and end slices. This was done by analyzing if there was overlap of the 95% confidence interval of each element. If the intervals overlap for each element for the end and the middle, the pipes are considered homogenous. According to the data, all of the pipes are homogenous. Appendix 7 shows the calculated 95% confidence intervals of all of the samples at all elements by counts.

The pipes were then analyzed by pair-wise comparison. Since the pipes are homogeneous, the average value for all analyzed portions each pipe was used. If a significant number of samples were indistinguishable they were rejected for that elemental comparison. This can be seen with Phosphorus which could only four samples could be differentiated. Refer to Appendix 8 for this comparison.

This comparison evaluated, between each sample, if it is possible to differentiate by one element at a time. For example, comparing pipe 1-1 and 2-3, by reviewing their chromium concentrations, these pipes can be differentiated. Appendix 8 shows the pair-wise comparison charts for multiple elements and combinations of elements for all of the samples. On the chart 'yes' means that there is overlap between the confidence intervals and that they cannot be differentiated, while 'no' means that the counts are different, the intervals do not overlap and the samples can be differentiated. Of the 37 total samples compared copper can be used to differentiate 136 or 20% of the samples, while manganese can differentiate 272 samples or 41%.

Nickel differentiates 173 samples, or 26%. Titanium can differentiate 70 samples or 11%. Chromium was found to be the most discriminating, by differentiating 382 samples or 57%.

However when combining the comparisons a higher number of samples can be differentiated. Comparing chromium, manganese, and copper 517 samples can be differentiated or 78%. Comparing chromium, manganese, copper, nickel and cobalt 532 samples or 80% can be differentiated.

Discussion

X-ray vs. SEM

Electrons from the SEM and X-ray excitation were used to analyze the standards and samples. Though SEM is a valuable technique for bulk analysis, it is not sensitive enough for low level concentrations. Using the higher energy of X-ray allowing for peaks of low concentration elements to be visualized and analyzed. As seen in Spectrum 3 when the same sample is bombarded with X-rays multiple small peaks are able to be seen (Spectrum 4) that were not evident in Spectrum 3.

LA-ICP-MS

Laser Ablation-ICP-MS is a highly sensitive analytical technique which allows the detection of elements down to less than 1 part per million. The LA-ICP-MS analysis on the five pipes provided benchmark data of suitable elements to be used when applying the X-ray technique. Due to only one sample analysis on each portion of the pipes the LA-ICP-MS data were not used for comparison.

X-ray

All of the samples' data was analyzed for homogeneity within the pipe. It can be said with 95% confidence that each pipe tested is homogenous throughout its length given the

technique applied. Once homogeneity was established it was possible to compare the inter-variability of the pipes. Upon the start of this research it was hypothesized that at the very least pipes would be able to be differentiated according to their brand. The research, however, shows that is not the case. The pipes cannot be differentiated solely on their brand, but can be differentiated more specifically by individual pipe. Just one example of this is shown in Table 8.

Sample	1-1	1-2	1-3
1-1	-	Differentiated	No
1-2	Differentiated	-	Differentiated

Table 8. Pipes 1 compared for differentiation

Pipe 2-1, 2-2, and 2-3 are also LDR pipes bought at the same location of each other but a different location than pipes 1-1, 1-2, and 1-3. Pipe 2-1 can be differentiated from 2-2, but not 2-3. Pipe 2-2 can be differentiated from 2-3.

Sample	2-1	2-2	2-3
2-1	-	Differentiated	No
2-2	Differentiated	-	Differentiated

Table 9. Pipes 2 compared for differentiation

Looking at these two examples brand and location has no effect on the differentiation of pipes. These results are reflected throughout the entire sample set.

Furthermore, samples 11-1, 11-2, and 11-3 can be differentiated from all but 2 samples. The pipes in this sample set are all from the same location and are Mueller B&K brand. This is not an uncommon brand. Sample 5-1 can be differentiated from all other samples. This sample is Mueller B&K, and also is not an uncommon brand. Also, samples 5-1, 5-2, and 5-3 can all be differentiated from each other. These pipes were all bought at the same location on the same day, from the same box. Mueller B&K and Proline were brands that were tested from more than one location, adding to the conclusion that brand cannot be correlated to trace elemental composition.

Reviewing the pair-wise comparisons Samples 8-2 and 8-3 can be differentiated from all other pipes. These pipes were of unknown brands from China and Ukraine emphasizing the effect of elemental composition on origin. However, due to the same brands and same store

location pipes being able to be differentiated, origin cannot be used as a sole discriminating factor.

It was found that just by comparison of titanium, samples 5-1 and 5-3 can be differentiated from all other samples except for each other. Titanium is being identified at 4.505keV.

Figure 18. Spectra of Samples 5-1 and 5-3 at the titanium peak

Figure 18 shows the overlap of the confidence intervals in the titanium peaks between samples 5-1 and 5-3, confirming that the samples cannot be differentiated from each other by this elemental comparison. Figure 19 shows the differentiation between 5-2 and the other two samples. Figure 19 also identifies the confidence intervals of each sample at the titanium peak represented by the vertical lines. The confidence interval for 5-2 does not overlap either interval for 5-1 or 5-3, and thus is differentiated from these samples.

Figure 19. Spectra of Samples 5-1, 5-2 and 5-3 at the titanium peak

Figure 20 exemplifies the comparison of manganese, at energy 5.89keV, for sample 5-3 and 10-2. The confidence intervals of the samples, shown as vertical lines, do not overlap, thus they can be differentiated.

Figure 20. Spectra of samples 5-3 and 10-2 at the manganese peak.

The method used in this research was able to differentiate 80% of the total samples, leading to the conclusion that the elemental composition of pipes is not unique between individual pipes. However there is enough variation among pipes to be useful. It would be possible to differentiate between a piece of pipe at a bomb scene and a collected pipe from a suspect's home based on differences of their elemental composition.

Spectra generated using X-ray excitation do not present Bremsstrahlung as present in spectra generated using electron excitation, however the x-ray spectra are not completely free of artifacts.

Figure 21. Standard BS-41 showing artifacts

Artifacts in the standard and sample spectra include silicon peaks, tube peaks, Compton scatter, sum peaks, and escape peaks. The iron escape peaks are due to the X-rays interacting with the silicon detector producing peaks that are of the value of an iron $K\alpha$ photon minus the silicon $K\alpha$ photon value. The Rh tube peaks are due to the X-rays generated from the target inside of the X-ray tube, which is made of rhodium. These x-rays are then elastically scattered by the atoms in the sample. This is also referred to as Rayleigh scatter. Compton scatter is the inelastic scatter of

the Rh tube peaks, which lose a small amount of energy during the interaction. When analyzing standards and samples none of these escape peaks are taken into consideration.

Sum peaks of iron are also present. Sum peaks are a result of two photons arriving at the detector immediately after one another and the detector cannot differentiate between the two. Their values are hence combined. The peak at 12.8keV is a result of two $K\alpha$ photons ($6.39 * 2 = 12.8$) being counted together. The peak at 13.457 is a result of a $K\alpha$ and a $K\beta$ photon hitting the detector immediately following one another ($6.39 + 7.058 = 13.457$). The sum peaks are not counted when calculating concentrations. Also diffraction peaks can be seen in the spectra, these peaks are from the interaction of the x-ray with the crystal structure of the metal. These peaks are not taken into account in this method, as the Giessen-Gordon method (35) is a more appropriate approach to analyzing diffraction and will not be addressed within this research.

Conclusions

Using X-rays as an alternate excitation to the electron gun of a SEM is a much more sensitive method and allows for elements of much lower concentrations to be analyzed. Though X-rays increase sensitivity over basic SEM they are not as sensitive as when using LA-ICP-MS for analysis. X-rays are sensitive enough, however, to get useful results. Using this method of X-rays and in comparison to LA-ICP-MS similar data was obtained from both methods in that differentiation of the pipes was possible, leading to the conclusion that using X-ray excitation can be used for trace elemental analysis. This research has shown that it may be in a laboratory's best interest to add an X-ray tube to an existing SEM for trace elemental analysis versus purchasing a much more expensive LA-ICP-MS system.

This method has found that pipes are homogenous throughout and are able to be used for comparison between pipes.

This method has also found that pipes cannot be differentiated by brand, but can to some extent be differentiated by pipe. The method can differentiate a sample set of 37 pipes to 80%. This method cannot link a pipe's trace elemental composition to brand or origin, but can partially differentiate between pipes. This method can be applied to when a pipe bomb is collected and pipe material from a suspect is collected. These pieces of evidence can be compared to each other using this method. This comparison can exclude the possibility that the two came from the same source, or it can add to the weight of evidence that it is possible the two came from the same source. The method cannot state that two pipes are the same as this method does not give 100% differentiation between pipes. Also since the post-blast pipes were unable to be analyzed before the end of this research project, it cannot be said how pre and post-blast pipe compares.

Future work

Though samples were sent to the FBI's Explosives Unit for detonation, scheduling did not allow for these samples to be returned in time for analysis before the defense of this thesis. Once the samples are returned, they will be analyzed according the X-ray method above, and compared to pre-blast portions of the pipe. Portions of the pipes were detonated using the more common low explosives, but also a high explosive. Three brands of pipe were detonated with low explosives, and one duplicate brand was separately exploded with high explosives. Pipes were halved, one half was analyzed pre-blast, and one half was used for an explosion and analyzed post blast to determine if the compositional homogeneity of the pipe changes due to the high heat and pressure of explosion

Future work should also include repeating the analyses of the pipes using x-rays over a variety of energies from 10keV to 50keV, and not just at 50keV. This is needed to address the difference in the efficiency of excitation at different energies depending on the element of interest, and possibly providing more accurate data.

More extensive research with a larger, more diverse sample set should be pursued to add to the weight of conclusions of this research. More research can be done using X-ray excitation for low level concentrations of elements in other solid samples. This method could potentially be used in glass analysis, concrete, etc. This method could be applied to a variety of fields and not just forensics for the comparison of pipe bombs.

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Appendix 1

Sample Preparation Machines Used

Photo1: Buehler Ltd. Cutter 10-1030

Photo 2: Buehler Ltd. Cutter, inside, cutting blade

Photo 3: Cutter set to cut a pipe in half

Photo 4: Buehler SimpliMet 3000 Automatic Mounting Press

Photo 5: Buehler Euromet I/EcometIV 8-sample polisher/grinder

Photo 6: Buehler Ecomet Variable Speed Grinder/Polisher

Appendix 2

Ti							V						
Row Labels	Average	SD	Low CI	High CI	# analyses	t	Row Labels	Average	SD	Low CI	High CI	# analyses	t
11	26	3.7	24	29	10	2.26216	11	56	17.7	43	68	10	2.26216
12	29	6.8	22	36	6	2.57058	12	58	19.3	37	78	6	2.57058
13	32	2.7	29	35	6	2.57058	13	60	17.9	41	78	6	2.57058
21	30	5.6	24	36	6	2.57058	21	60	15.0	44	76	6	2.57058
22	33	5.6	27	39	6	2.57058	22	55	10.9	44	67	6	2.57058
23	25	6.3	18	31	6	2.57058	23	77	35.8	40	115	6	2.57058
31	26	4.8	20	31	6	2.57058	31	72	11.8	59	84	6	2.57058
32	25	5.7	19	31	6	2.57058	32	68	15.9	51	84	6	2.57058
33	30	6.8	23	37	6	2.57058	33	74	11.1	62	86	6	2.57058
41	26	5.0	22	29	10	2.26216	41	60	11.9	52	69	10	2.26216
42	28	4.4	23	32	6	2.57058	42	85	29.8	54	116	6	2.57058
43	23	9.2	14	33	6	2.57058	43	88	34.0	53	124	6	2.57058
51	63	10.7	52	74	6	2.57058	51	67	3.5	63	71	6	2.57058
52	29	4.0	25	33	6	2.57058	52	71	23.2	46	95	6	2.57058
53	54	9.3	44	63	6	2.57058	53	71	7.7	63	79	6	2.57058
61	31	7.8	23	40	6	2.57058	61	70	15.1	54	85	6	2.57058
62	30	7.8	21	38	6	2.57058	62	73	17.6	54	91	6	2.57058
63	27	5.8	20	33	6	2.57058	63	88	18.8	68	108	6	2.57058
71	28	5.3	22	34	6	2.57058	71	72	18.0	53	91	6	2.57058
72	31	8.7	22	40	6	2.57058	72	81	21.5	58	103	6	2.57058
73	27	4.2	23	32	6	2.57058	73	78	30.9	46	110	6	2.57058
81	30	3.7	26	34	6	2.57058	81	60	15.7	44	76	6	2.57058
82	30	6.5	23	37	6	2.57058	82	76	23.8	51	101	6	2.57058
83	29	5.8	24	33	10	2.26216	83	80	29.2	59	101	10	2.26216
91	32	3.3	29	36	6	2.57058	91	61	15.9	44	78	6	2.57058
92	30	9.5	20	40	6	2.57058	92	68	20.4	47	90	6	2.57058
93	30	3.7	26	34	6	2.57058	93	85	37.6	45	124	6	2.57058
101	31	7.7	22	39	6	2.57058	101	59	30.9	26	91	6	2.57058
102	29	4.1	26	32	10	2.26216	102	67	24.1	50	85	10	2.26216
103	32	4.6	27	37	6	2.57058	103	57	52.6	2	112	6	2.57058
111	28	4.0	24	33	6	2.57058	111	80	32.1	46	113	6	2.57058
112	28	3.2	25	32	6	2.57058	112	75	18.4	55	94	6	2.57058
113	33	5.7	27	39	6	2.57058	113	74	14.0	59	88	6	2.57058
121	31	5.5	26	37	6	2.57058	121	76	19.0	56	96	6	2.57058
122	27	2.0	25	29	6	2.57058	122	72	28.6	42	102	6	2.57058
123	29	3.3	25	32	6	2.57058	123	66	15.2	50	82	6	2.57058
131	31	5.8	26	35	10	2.26216	131	95	128.8	3	188	10	2.26216

Mn							Co						
Row Labels	Average	SD	Low CI	High CI	# analyses	t	Row Labels	Average	SD	Low CI	High CI	# analyses	t
11	375	32.7	351	398	10	2.26216	11	1907	68.5	1858	1956	10	2.26216
12	366	26.1	338	393	6	2.57058	12	1936	162.6	1765	2106	6	2.57058
13	446	75.2	367	525	6	2.57058	13	1872	66.5	1802	1941	6	2.57058
21	377	23.4	352	401	6	2.57058	21	1904	56.0	1845	1963	6	2.57058
22	373	10.2	362	384	6	2.57058	22	1906	38.1	1866	1946	6	2.57058
23	347	17.5	329	365	6	2.57058	23	1907	39.8	1865	1949	6	2.57058
31	368	24.8	341	394	6	2.57058	31	1915	34.9	1878	1951	6	2.57058
32	382	50.5	329	435	6	2.57058	32	1907	67.4	1836	1978	6	2.57058
33	360	19.9	339	381	6	2.57058	33	1862	21.7	1839	1885	6	2.57058
41	372	17.6	360	385	10	2.26216	41	1865	41.7	1835	1895	10	2.26216
42	386	53.8	329	442	6	2.57058	42	1869	57.8	1809	1930	6	2.57058
43	389	25.2	362	415	6	2.57058	43	1860	61.7	1795	1925	6	2.57058
51	351	14.8	335	366	6	2.57058	51	1877	43.4	1832	1923	6	2.57058
52	281	14.1	266	295	6	2.57058	52	1929	60.9	1865	1993	6	2.57058
53	325	7.7	317	333	6	2.57058	53	1888	60.8	1824	1952	6	2.57058
61	311	16.3	294	328	6	2.57058	61	1901	35.4	1863	1938	6	2.57058
62	357	15.9	340	373	6	2.57058	62	1885	47.4	1836	1935	6	2.57058
63	369	18.6	349	388	6	2.57058	63	1866	71.5	1791	1941	6	2.57058
71	349	38.6	309	390	6	2.57058	71	1904	52.3	1849	1959	6	2.57058
72	366	27.6	337	395	6	2.57058	72	1857	59.6	1794	1919	6	2.57058
73	259	21.9	236	282	6	2.57058	73	1847	19.0	1827	1867	6	2.57058
81	367	29.9	335	398	6	2.57058	81	1862	109.8	1746	1977	6	2.57058
82	278	25.8	251	305	6	2.57058	82	1852	82.1	1766	1938	6	2.57058
83	302	24.2	285	320	10	2.26216	83	1940	62.6	1895	1985	10	2.26216
91	297	23.0	273	321	6	2.57058	91	1869	83.0	1782	1956	6	2.57058
92	306	36.0	269	344	6	2.57058	92	1921	80.0	1837	2005	6	2.57058
93	353	43.6	307	399	6	2.57058	93	1888	83.4	1800	1975	6	2.57058
101	424	185.8	229	619	6	2.57058	101	1859	34.3	1823	1895	6	2.57058
102	403	27.4	383	422	10	2.26216	102	1936	82.8	1876	1995	10	2.26216
103	402	28.3	372	432	6	2.57058	103	1912	73.5	1834	1989	6	2.57058
111	226	13.2	212	240	6	2.57058	111	1634	63.0	1568	1700	6	2.57058
112	251	32.5	217	285	6	2.57058	112	1759	192.8	1556	1961	6	2.57058
113	241	30.9	208	273	6	2.57058	113	1941	127.2	1807	2074	6	2.57058
121	304	43.8	258	350	6	2.57058	121	1923	34.2	1887	1959	6	2.57058
122	328	35.4	291	365	6	2.57058	122	1910	29.7	1879	1942	6	2.57058
123	323	31.9	289	356	6	2.57058	123	1890	73.9	1812	1967	6	2.57058
131	379	22.6	363	395	10	2.26216	131	1890	45.9	1857	1923	10	2.26216

Cu							Ge						
Row Labels	Average	SD	Low CI	High CI	# analyses	t	Row Labels	Average	SD	Low CI	High CI	# analyses	t
11	11	3.5	9	14	10	2.26216	11	8	2.8	6	10	10	2.26216
12	11	3.3	7	14	6	2.57058	12	6	3.1	3	9	6	2.57058
13	13	4.8	8	18	6	2.57058	13	7	2.9	3	10	6	2.57058
21	8	2.5	5	10	6	2.57058	21	6	2.3	3	8	6	2.57058
22	7	3.0	4	10	6	2.57058	22	6	3.0	3	9	6	2.57058
23	6	1.3	5	8	6	2.57058	23	8	3.4	4	11	6	2.57058
31	9	2.7	6	12	6	2.57058	31	9	3.9	5	13	6	2.57058
32	8	1.7	6	10	6	2.57058	32	8	3.0	4	11	6	2.57058
33	11	2.1	8	13	6	2.57058	33	7	2.4	5	9	6	2.57058
41	8	2.5	6	10	10	2.26216	41	7	1.6	6	8	10	2.26216
42	5	2.0	3	7	6	2.57058	42	10	3.0	7	13	6	2.57058
43	7	1.8	5	9	6	2.57058	43	11	5.0	5	16	6	2.57058
51	21	7.2	14	29	6	2.57058	51	19	6.0	12	25	6	2.57058
52	11	1.0	9	12	6	2.57058	52	8	2.9	5	11	6	2.57058
53	19	6.4	12	26	6	2.57058	53	15	4.0	10	19	6	2.57058
61	8	3.3	4	11	6	2.57058	61	10	3.7	6	14	6	2.57058
62	9	3.7	5	13	6	2.57058	62	8	2.5	6	11	6	2.57058
63	8	2.0	6	10	6	2.57058	63	8	3.3	4	11	6	2.57058
71	10	3.7	6	14	6	2.57058	71	9	2.3	6	11	6	2.57058
72	8	0.8	7	9	6	2.57058	72	7	3.1	4	11	6	2.57058
73	13	3.3	9	16	6	2.57058	73	11	4.9	6	16	6	2.57058
81	13	2.3	10	15	6	2.57058	81	7	1.7	5	9	6	2.57058
82	22	3.9	17	26	6	2.57058	82	9	2.1	7	12	6	2.57058
83	26	4.3	23	29	10	2.26216	83	8	2.9	6	10	10	2.26216
91	8	2.0	6	10	6	2.57058	91	7	2.9	4	10	6	2.57058
92	9	1.5	7	10	6	2.57058	92	8	3.5	4	12	6	2.57058
93	9	1.9	7	11	6	2.57058	93	8	3.3	4	11	6	2.57058
101	10	3.4	7	14	6	2.57058	101	6	2.6	3	9	6	2.57058
102	14	3.8	11	17	10	2.26216	102	9	3.4	7	12	10	2.26216
103	12	2.9	9	15	6	2.57058	103	9	5.2	4	15	6	2.57058
111	8	3.2	5	12	6	2.57058	111	8	3.3	5	12	6	2.57058
112	8	2.8	5	11	6	2.57058	112	7	1.5	6	9	6	2.57058
113	7	1.0	6	8	6	2.57058	113	9	2.1	7	11	6	2.57058
121	10	4.1	6	14	6	2.57058	121	10	6.0	4	16	6	2.57058
122	8	1.0	7	9	6	2.57058	122	8	3.9	4	12	6	2.57058
123	8	4.2	4	13	6	2.57058	123	8	2.0	6	10	6	2.57058
131	11	4.5	8	14	10	2.26216	131	9	5.6	5	13	10	2.26216

Sn							Sb						
Row Labels	Average	SD	Low CI	High CI	# analyses	t	Row Labels	Average	SD	Low CI	High CI	# analyses	t
11	2	1.3	1	3	10	2.26216	11	3	1.6	1	4	10	2.26216
12	2	1.2	1	3	6	2.57058	12	1	0.8	0	2	6	2.57058
13	2	1.4	0	3	6	2.57058	13	2	0.8	1	3	6	2.57058
21	3	2.7	0	5	6	2.57058	21	2	0.8	1	2	6	2.57058
22	3	1.2	1	4	6	2.57058	22	1	0.5	1	2	6	2.57058
23	2	0.8	1	2	6	2.57058	23	2	0.5	1	2	6	2.57058
31	2	1.0	0	3	6	2.57058	31	1	0.8	0	2	6	2.57058
32	1	0.8	0	2	6	2.57058	32	2	1.2	0	3	6	2.57058
33	2	2.0	0	4	6	2.57058	33	2	1.0	0	3	6	2.57058
41	2	0.7	1	2	10	2.26216	41	2	1.4	0	3	10	2.26216
42	1	1.0	0	2	6	2.57058	42	3	1.8	1	5	6	2.57058
43	2	2.0	0	4	6	2.57058	43	1	0.4	1	2	6	2.57058
51	2	1.0	0	3	6	2.57058	51	1	1.4	0	3	6	2.57058
52	2	1.5	0	3	6	2.57058	52	1	0.8	0	2	6	2.57058
53	4	1.9	2	5	6	2.57058	53	3	2.0	1	5	6	2.57058
61	2	1.3	0	3	6	2.57058	61	2	1.0	1	3	6	2.57058
62	2	1.0	1	3	6	2.57058	62	1	1.2	0	2	6	2.57058
63	2	1.5	0	3	6	2.57058	63	2	1.4	0	3	6	2.57058
71	2	1.6	1	4	6	2.57058	71	1	1.0	0	2	6	2.57058
72	2	1.0	1	3	6	2.57058	72	4	1.9	2	5	6	2.57058
73	2	1.7	0	4	6	2.57058	73	3	1.2	2	4	6	2.57058
81	2	1.2	1	3	6	2.57058	81	2	0.8	1	3	6	2.57058
82	3	1.2	1	4	6	2.57058	82	2	1.5	1	4	6	2.57058
83	2	1.2	1	3	10	2.26216	83	2	1.8	1	3	10	2.26216
91	1	1.2	0	2	6	2.57058	91	2	0.8	1	3	6	2.57058
92	1	0.8	0	2	6	2.57058	92	2	1.4	0	3	6	2.57058
93	1	0.9	0	2	6	2.57058	93	1	0.8	0	2	6	2.57058
101	2	1.3	0	3	6	2.57058	101	2	1.3	0	3	6	2.57058
102	2	1.5	1	3	10	2.26216	102	2	1.5	1	3	10	2.26216
103	3	1.4	1	4	6	2.57058	103	3	1.4	1	4	6	2.57058
111	2	1.2	0	3	6	2.57058	111	2	1.2	0	3	6	2.57058
112	2	0.8	1	3	6	2.57058	112	2	0.8	1	3	6	2.57058
113	2	1.2	1	3	6	2.57058	113	2	1.2	1	3	6	2.57058
121	2	1.4	0	3	6	2.57058	121	2	1.4	0	3	6	2.57058
122	2	1.2	0	3	6	2.57058	122	2	1.2	0	3	6	2.57058
123	2	0.9	1	3	6	2.57058	123	2	0.9	1	3	6	2.57058
131	1	1.4	0	2	10	2.26216	131	1	1.4	0	2	10	2.26216

P						
Row Labels	Average	SD	Low CI	High CI	# analyses	t
11	9	2.7	7	11	10	2.26216
12	8	2.4	6	11	6	2.57058
13	10	2.2	8	13	6	2.57058
21	10	1.9	8	11	6	2.57058
22	7	2.6	4	10	6	2.57058
23	9	2.8	6	11	6	2.57058
31	9	2.1	6	11	6	2.57058
32	9	3.1	5	12	6	2.57058
33	8	2.4	6	10	6	2.57058
41	10	2.0	8	11	10	2.26216
42	6	1.7	4	8	6	2.57058
43	8	3.2	5	11	6	2.57058
51	12	3.3	8	16	6	2.57058
52	9	1.8	7	11	6	2.57058
53	10	1.9	8	12	6	2.57058
61	9	1.7	7	11	6	2.57058
62	7	1.5	6	9	6	2.57058
63	8	1.8	6	10	6	2.57058
71	9	5.2	3	14	6	2.57058
72	9	3.1	6	12	6	2.57058
73	11	4.7	6	15	6	2.57058
81	10	2.6	7	13	6	2.57058
82	8	2.9	5	11	6	2.57058
83	10	3.3	8	12	10	2.26216
91	7	2.6	4	10	6	2.57058
92	6	2.4	3	8	6	2.57058
93	6	2.9	3	9	6	2.57058
101	7	1.5	5	8	6	2.57058
102	9	2.6	7	11	10	2.26216
103	8	1.5	7	10	6	2.57058
111	11	1.9	9	12	6	2.57058
112	8	4.1	4	12	6	2.57058
113	9	2.4	6	11	6	2.57058
121	8	3.1	5	11	6	2.57058
122	10	2.2	7	12	6	2.57058
123	6	1.9	4	8	6	2.57058
131	7	2.9	5	9	10	2.26216

Appendix 3

All LA-ICP-MS Data

Results are in Parts per Million

Low Res 1	1-1-C- A	1-1-C-B	4-1-C-A	4-1-C-B	8-3-C-A	8-3-C-B	10-2-C-A	10-2-C-B	13-1-C-A	13-1-C-B
Mn	3946	4050	4540	3975	4731	4047	4404	4538	3943	3837
Fe	950000	950000	950000	950000	950000	950000	950000	950000	950000	950000
As	40	42	28	26	69	69	22	22	29	29
Zr	1.5	1.6	2.4	2.3	1.1	1.6	1.7	2.2	0.79	1.2
Nb	0.68	0.75	0.95	0.90	<0.27	<0.39	1.1	1.2	0.54	0.52
Mo	24	25	6.3	5.3	42	40	23	25	53	54
Ag	<0.41	<0.43	<0.40	<0.46	0.57	0.49	<0.32	<0.45	<0.47	<0.41
Sn	8.4	8.5	77	64	41	37	15	17	72	71
Sb	14	15	4.4	3.7	17	15	4.2	4.7	8.3	7.9
Ce	<0.02	<0.03	<0.03	<0.04	<0.03	0.035	<0.02	0.026	<0.03	<0.03
W	1.9	1.9	5.6	4.8	20	19	3.9	3.9	2.0	1.9
Pb 204	<4.26	<3.89	<4.79	<4.48	<4.07	<5.69	<3.70	<3.08	<4.65	<3.90
Pb 206	0.29	0.27	0.33	0.34	1.0	1.4	0.42	0.55	0.51	0.63
Pb 207	0.27	0.29	0.33	0.33	1.1	1.5	0.41	0.54	0.49	0.71
Pb 208	0.30	0.35	0.35	0.35	1.1	1.4	0.39	0.55	0.52	0.65
Bi	<0.12	<0.10	<0.08	<0.12	<0.09	0.40	<0.06	<0.08	<0.08	<0.13

Low Res 2	1-1-C- A	1-1-C-B	4-1-C-A	4-1-C-B	8-3-C-A	8-3-C-B	10-2-C-A	10-2-C-B	13-1-C-A	13-1-C-B
Mn	4163	4264	4810	4203	4927	4205	4626	4756	4124	4004
Fe	950000	950000	950000	950000	950000	950000	950000	950000	950000	950000
As	49	51	34	31	86	85	27	27	36	35
Mo	30	31	8.1	6.8	50	47	28	30	65	65
Ag	<0.06	<0.06	<0.06	<0.06	0.10	0.097	<0.04	<0.06	<0.07	<0.06
W	2.0	2.0	6.0	5.1	20	19	4.1	4.1	2.1	1.9
Re	0.0012	0.0047	<0.02	0.0039	0.0038	<0.03	<0.01	<0.03	0.0055	0.0035

Med Res 1	1-1-C- A	1-1-C-B	4-1-C-A	4-1-C-B	8-3-C-A	8-3-C-B	10-2-C-A	10-2-C-B	13-1-C-A	13-1-C-B
P	224	228	263	295	135	241	118	158	97	88
Ti	<45.38	53	49	65	<68.47	2306	<65.37	105	<67.98	<51.48
Ti	<57.76	<41.40	139	83	<79.22	2447	107	135	<92.16	<63.54
V	27	28	26	34	6.0	<8.28	8.1	11	<5.02	<6.48
Cr 52	278	293	383	406	440	457	351	365	261	303
Cr 53	287	312	390	444	441	465	363	352	252	286
Mn	4055	3822	4358	4217	4786	4693	4325	4358	3758	3944
Fe 56	950000	950000	950000	950000	950000	950000	950000	950000	950000	950000
Fe 57	938020	886787	934332	934750	1001131	967173	928381	740709	952297	918557
Co	81	74	42	43	59	50	18	20	22	24
Ni 60	145	138	131	145	405	365	80	93	130	132
Ni 62	210	125	<137.05	164	413	351	107	83	146	137
Cu 63	149	138	66	82	799	722	220	247	250	247
Cu 65	257	170	62	96	803	747	225	245	239	277
Zn 66	1.2	1.3	1.6	1.8	1.2	1.4	1.0	1.6	1.3	1.3
Zn 67	1.3	1.5	2.3	2.5	1.3	1.3	1.1	1.9	<1.63	1.3
Zn 68	1.1	1.5	1.8	1.8	1.3	1.4	1.0	1.6	1.4	1.2
Ga 69	20	21	14	16	9.3	7.9	3.9	4.3	3.6	4.1
Ga 71	21	21	15	18	10	9.4	4.2	4.1	<3.76	<6.34
Ge 72	7.3	<11.06	7.2	7.5	<24.65	11	26	27	24	26
Ge 73	10	7.5	5.2	7.3	<16.36	10	18	26	34	14
Ge 74	<10.59	<7.61	6.1	7.4	14	9.3	29	31	34	28
As	56	41	29	25	114	84	23	21	30	28
Se	0.31	0.31	0.46	0.44	0.66	0.22	0.16	0.83	0	<11.91

Med Res 2	1-1-C- A	1-1-C-B	4-1-C-A	4-1-C-B	8-3-C-A	8-3-C-B	10-2-C-A	10-2-C-B	13-1-C-A	13-1-C-B
V	30	30	30	38	<6.16	<8.94	8.7	11	<5.42	<7.00
Cr 52	324	342	447	474	513	532	410	425	304	353
Cr 53	330	360	448	511	514	543	419	408	293	333
Mn	4137	3887	4474	4315	4791	4684	4385	4405	3786	3961
Fe 56	950000	950000	950000	950000	950000	950000	950000	950000	950000	950000
Fe 57	934270	886734	923293	927351	1021083	990374	932000		963603	933154
Co	56	51	30	30	39	33	12	14	15	16
Ni	295	174	<188.19	231	545	458	147	113	196	183
Cu 63	77	69	36	44	338	295	106	116	113	108
Cu 65	134	86	35	52	343	308	110	116	109	122
Zn 66	0.13	0.14	0.18	0.20	0.13	0.15	0.11	0.17	0.15	0.14
Zn 67	0.13	0.15	0.24	0.25	0.12	0.11	0.10	0.18	<0.16	0.12
Zn 68	0.12	0.16	0.21	0.20	0.14	0.15	0.11	0.17	0.15	0.13
Ga 69	22	23	16	18	9.9	8.4	4.3	4.7	3.9	4.5
Ga 71	23	23	15	19	12	11	4.7	4.7	<4.19	<7.06
Ge 72	11	<16.30	11	11	<36.34	16	37	39	34	37
Ge 73	19	14	9.4	13	<31.04	20	34	50	65	28
Ge 74	<13.65	<9.81	7.8	9.5	18	12	37	39	43	36
As	59	43	31	27	117	86	24	22	31	29

Appendix 4

LA-ICP-MS Data – only relevant elements

Results are in Parts per Million

Low Res 1	1-1-C- A	1-1-C-B	4-1-C-A	4-1-C-B	8-3-C-A	8-3-C-B	10-2-C-A	10-2-C-B	13-1-C-A	13-1-C-B
Mn	3946	4050	4540	3975	4731	4047	4404	4538	3943	3837
Fe	950000	950000	950000	950000	950000	950000	950000	950000	950000	950000
As	40	42	28	26	69	69	22	22	29	29
Mo	24	25	6.3	5.3	42	40	23	25	53	54
Sn	8.4	8.5	77	64	41	37	15	17	72	71
Sb	14	15	4.4	3.7	17	15	4.2	4.7	8.3	7.9

Low Res 2	1-1-C- A	1-1-C-B	4-1-C-A	4-1-C-B	8-3-C-A	8-3-C-B	10-2-C-A	10-2-C-B	13-1-C-A	13-1-C-B
Mn	4163	4264	4810	4203	4927	4205	4626	4756	4124	4004
Fe	950000	950000	950000	950000	950000	950000	950000	950000	950000	950000
As	49	51	34	31	86	85	27	27	36	35
Mo	30	31	8.1	6.8	50	47	28	30	65	65

Med Res 1	1-1-C- A	1-1-C-B	4-1-C-A	4-1-C-B	8-3-C-A	8-3-C-B	10-2-C-A	10-2-C-B	13-1-C-A	13-1-C-B
P	224	228	263	295	135	241	118	158	97	88
Ti 47	<45.38	53	49	65	<68.47	2306	<65.37	105	<67.98	<51.48
Ti 49	<57.76	<41.40	139	83	<79.22	2447	107	135	<92.16	<63.54
V	27	28	26	34	6.0	<8.28	8.1	11	<5.02	<6.48
Cr 52	278	293	383	406	440	457	351	365	261	303
Cr 53	287	312	390	444	441	465	363	352	252	286
Mn	4055	3822	4358	4217	4786	4693	4325	4358	3758	3944
Fe 56	950000	950000	950000	950000	950000	950000	950000	950000	950000	950000
Fe 57	938020	886787	934332	934750	1001131	967173	928381	740709	952297	918557
Co	81	74	42	43	59	50	18	20	22	24
Ni 60	145	138	131	145	405	365	80	93	130	132
Ni 62	210	125	<137.05	164	413	351	107	83	146	137
Cu 63	149	138	66	82	799	722	220	247	250	247
Cu 65	257	170	62	96	803	747	225	245	239	277
Ga 69	20	21	14	16	9.3	7.9	3.9	4.3	3.6	4.1
Ga 71	21	21	15	18	10	9.4	4.2	4.1	<3.76	<6.34
Ge 72	7.3	<11.06	7.2	7.5	<24.65	11	26	27	24	26
Ge 73	10	7.5	5.2	7.3	<16.36	10	18	26	34	14
Ge 74	<10.59	<7.61	6.1	7.4	14	9.3	29	31	34	28
As	56	41	29	25	114	84	23	21	30	28

Med Res 2	1-1-C- A	1-1-C-B	4-1-C-A	4-1-C-B	8-3-C-A	8-3-C-B	10-2-C-A	10-2-C-B	13-1-C-A	13-1-C-B
V	30	30	30	38	<6.16	<8.94	8.7	11	<5.42	<7.00
Cr 52	324	342	447	474	513	532	410	425	304	353
Cr 53	330	360	448	511	514	543	419	408	293	333
Mn	4137	3887	4474	4315	4791	4684	4385	4405	3786	3961
Fe 56	950000	950000	950000	950000	950000	950000	950000	950000	950000	950000
Fe 57	934270	886734	923293	927351	1021083	990374	932000	-	963603	933154
Co	56	51	30	30	39	33	12	14	15	16
Ni	295	174	<188.19	231	545	458	147	113	196	183
Cu 63	77	69	36	44	338	295	106	116	113	108
Cu 65	134	86	35	52	343	308	110	116	109	122
Ga 69	22	23	16	18	9.9	8.4	4.3	4.7	3.9	4.5
Ga 71	23	23	15	19	12	11	4.7	4.7	<4.19	<7.06
Ge 72	11	<16.30	11	11	<36.34	16	37	39	34	37
Ge 73	19	14	9.4	13	<31.04	20	34	50	65	28
Ge 74	<13.65	<9.81	7.8	9.5	18	12	37	39	43	36
As	59	43	31	27	117	86	24	22	31	29

Appendix 5

Elemental comparison of samples using LA-ICP-MS data

Graph 1. Cobalt versus Nickel

Graph 2. Copper versus Germanium

Graph 3. Titanium versus Copper

Graph 4. Vanadium versus Molybdenum

Graph 5. Molybdenum versus Tin

Graph 6. Titanium versus Molybdenum

Appendix 6

Duplicate analysis via X-ray on 5 major samples

(shown as weight percent)

	1-1 Dup 1	1-1 Dup 2	Average	StdDev	1-1 B Dup 1	1-1 B Dup 2	Average	StdDev	4-1A Dup 1	4-1A Dup 2	Average	StdDev	4-1B Dup 1	4-1B Dup 2	Average	StdDev
P	0.008	0.004	0.006	0.003	0.003	0.007	0.005	0.003	0.005	0.004	0.005	0.001	0.002	0.005	0.004	0.002
Ti	0.008	0.008	0.008	0.000	0.008	0.006	0.007	0.001	0.008	0.008	0.008	0.000	0.006	0.002	0.004	0.003
V	0.019	0.023	0.021	0.003	0.059	0.053	0.056	0.004	0.029	0.023	0.026	0.004	0.043	0.040	0.042	0.002
Cr	0.030	0.031	0.031	0.001	0.027	0.027	0.027	0.000	0.040	0.037	0.039	0.002	0.036	0.038	0.037	0.001
Mn	0.387	0.394	0.391	0.005	0.400	0.402	0.401	0.001	0.313	0.309	0.311	0.003	0.411	0.418	0.415	0.005
Fe	98.910	98.854	98.882	0.040	98.721	98.755	98.738	0.024	98.765	98.755	98.760	0.007	98.806	98.792	98.799	0.010
Co	0.357	0.376	0.367	0.013	0.392	0.374	0.383	0.013	0.409	0.471	0.440	0.044	0.361	0.320	0.341	0.029
Ni	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Cu	0.023	0.027	0.025	0.003	0.031	0.021	0.026	0.007	0.015	0.014	0.015	0.001	0.010	0.011	0.011	0.001
Ge	0.011	0.014	0.013	0.002	0.025	0.049	0.037	0.017	0.006	0.010	0.008	0.003	0.011	0.014	0.013	0.002
Mo	0.002	0.004	0.003	0.001	0.008	0.001	0.005	0.005	0.007	0.006	0.007	0.001	0.004	0.008	0.006	0.003
Sn	0.014	0.015	0.015	0.001	0.018	0.024	0.021	0.004	0.010	0.011	0.011	0.001	0.011	0.010	0.011	0.001
Sb	0.005	0.004	0.005	0.001	0.002	0.000	0.001	0.001	0.003	0.005	0.004	0.001	0.003	0.001	0.002	0.001

	8-3 A Dup 1	8-3A Dup 2	Average	StdDev	8-3B Dup 1	8-3B Dup2	Average	StdDev	10-2A Dup 1	10-2A Dup 2	Average	StdDev	10-2B Dup 1	10-2B Dup 2	Average	StdDev
P	0.000	0.005	0.003	0.004	0.014	0.004	0.009	0.007	0.003	0.008	0.006	0.004	0.006	0.003	0.005	0.002
Ti	0.012	0.003	0.008	0.006	0.008	0.005	0.007	0.002	0.017	0.005	0.011	0.008	0.008	0.008	0.008	0.000
V	0.026	0.018	0.022	0.006	0.071	0.076	0.074	0.004	0.041	0.037	0.039	0.003	0.049	0.052	0.051	0.002
Cr	0.043	0.040	0.042	0.002	0.027	0.028	0.028	0.001	0.032	0.037	0.035	0.004	0.025	0.033	0.029	0.006
Mn	0.254	0.241	0.248	0.009	0.294	0.276	0.285	0.013	0.440	0.436	0.438	0.003	0.389	0.485	0.437	0.068
Fe	98.878	98.938	98.908	0.042	98.633	98.698	98.666	0.046	98.745	98.845	98.795	0.071	98.700	98.629	98.665	0.050
Co	0.444	0.446	0.445	0.001	0.633	0.588	0.611	0.032	0.456	0.424	0.440	0.023	0.559	0.482	0.521	0.054
Ni	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Cu	0.085	0.091	0.088	0.004	0.073	0.067	0.070	0.004	0.030	0.024	0.027	0.004	0.034	0.039	0.037	0.004
Ge	0.010	0.005	0.008	0.004	0.030	0.033	0.032	0.002	0.012	0.010	0.011	0.001	0.030	0.033	0.032	0.002
Mo	0.012	0.007	0.010	0.004	0.003	0.007	0.005	0.003	0.008	0.003	0.006	0.004	0.000	0.006	0.003	0.004
Sn	0.018	0.012	0.015	0.004	0.016	0.021	0.019	0.004	0.004	0.008	0.006	0.003	0.015	0.016	0.016	0.001
Sb	0.005	0.006	0.006	0.001	0.002	0.002	0.002	0.000	0.004	0.004	0.004	0.000	0.000	0.000	0.000	0.000

	13-1A Dup 1	13-A Dup 2	Average	StdDev	13-1B Dup 1	13-1 Dup 2	Average	StdDev
P	0.000	0.002	0.001	0.001	0.003	0.003	0.003	0.000
Ti	0.005	0.012	0.009	0.005	0.010	0.004	0.007	0.004
V	0.030	0.031	0.031	0.001	0.027	0.025	0.026	0.001
Cr	0.031	0.028	0.030	0.002	0.028	0.024	0.026	0.003
Mn	0.433	0.425	0.429	0.006	0.434	0.415	0.425	0.013
Fe	98.777	98.863	98.820	0.061	98.829	98.903	98.866	0.052
Co	0.513	0.415	0.464	0.069	0.499	0.492	0.496	0.005
Ni	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Cu	0.031	0.030	0.031	0.001	0.037	0.032	0.035	0.004
Ge	0.009	0.007	0.008	0.001	0.017	0.012	0.015	0.004
Mo	0.001	0.009	0.005	0.006	0.006	0.002	0.004	0.003
Sn	0.008	0.011	0.010	0.002	0.005	0.008	0.007	0.002
Sb	0.001	0.002	0.002	0.001	0.003	0.001	0.002	0.001

Appendix 7

Confidence intervals for all samples

(Shown as counts)

Label	1-1 Dup 1	1-1 Dup 2	1-1 A Top	1-1 A Mid	1-1 A Bot					1-1 B Dup 1	1-1 B Dup 2	1-1 B Top	1-1 B Mid	1-1 B Bot				
Store	Menards									Menards								
Brand	LDR China									LDR China								
Location	Masslion, OH									Masslion, OH								
Slice	end									middle								
Spot	middle	middle	top	middle	bottom	Average	StdDev	95% conf interval		middle	middle	top	middle	bottom	Average	StdDev	95% Conf Inter	
P	9	5	6	8	10	8	1.9	5	10	12	12	6	12	8	10	2.5	7	13
Ti	33	26	23	20	26	26	4.3	20	31	29	26	25	24	30	27	2.6	24	30
V	41	43	34	51	52	44	6.7	36	52	90	79	66	45	55	67	18.0	45	89
Cr	93	82	83	86	67	82	8.5	72	93	87	76	87	74	71	79	7.5	70	88
Mn	343	416	373	401	375	382	25.2	350	413	402	409	360	316	350	367	38.5	320	415
Fe	50564	50696	50639	50269	50560	50546	147.2	50363	50728	49992	50105	50960	50617	50958	50526	459.8	49955	51097
Co	1952	2035	1840	1852	1926	1921	71.1	1833	2009	1924	1975	1822	1900	1846	1893	61.2	1817	1969
Ni	7	11	9	7	4	8	2.3	5	10	11	9	8	6	11	9	2.1	6	12
Cu	9	17	13	5	8	10	4.2	5	16	14	10	13	14	11	12	1.8	10	15
Ge	8	10	5	3	5	6	2.5	3	9	10	12	7	9	7	9	2.1	6	12
Mo	8	10	7	10	9	9	1.2	7	10	11	13	7	18	8	11	4.4	6	17
Sn	1	0	3	3	3	2	1.3	0	4	0	3	3	2	1	2	1.3	0	3
Sb	4	4	4	1	1	3	1.5	1	5	1	1	1	3	5	2	1.8	0	4

Label	1-2 A Top	1-2 A Mid	1-2 A Bot					1-2 B Top	1-2 B Mid	1-2 B Bot				
Store	Menards							Menards						
Brand	LDR China							LDR China						
Location	Masslion, OH							Masslion, OH						
Slice	end							middle						
Spot	top	middle	bottom	Average	StdDev	95% Conf Inter		top	middle	bottom	Average	StdDev	95% Conf Inter	
P	7	5	12	8	3.6	-1	17	9	9	7	8	1.2	5	11
Ti	33	26	17	25	8.0	5	45	30	34	35	33	2.6	26	40
V	59	47	91	66	22.7	9	122	65	35	49	50	15.0	12	87
Cr	154	162	170	162	8.0	142	182	157	171	180	169	11.6	141	198
Mn	342	356	368	355	13.0	323	388	409	340	380	376	34.6	290	462
Fe	50453	50841	50428	50574	231.6	49999	51149	50455	50641	48993	50030	902.6	47788	52272
Co	1860	1916	1908	1895	30.3	1819	1970	1779	1899	2251	1976	245.3	1367	2586
Ni	24	33	22	26	5.9	12	41	24	31	26	27	3.6	18	36
Cu	11	11	9	10	1.2	7	13	6	16	11	11	5.0	-1	23
Ge	5	8	10	8	2.5	1	14	5	7	1	4	3.1	-3	12
Mo	11	9	20	13	5.9	-1	28	14	8	20	14	6.0	-1	29
Sn	4	1	1	2	1.7	-2	6	1	2	2	2	0.6	0	3
Sb	2	0	1	1	1.0	-1	3	2	1	2	2	0.6	0	3

Label	1-3 A Top	1-3 A Mid	1-3 A Bot					1-3 B Top	1-3 B Mid	1-3 B Bot				
Store	Menards							Menards						
Brand	LDR China							LDR China						
Location	Masslion, OH							Masslion, OH						
Slice	end							middle						
Spot	top	middle	bottom	Average	StdDev	95% Conf Inter		top	middle	bottom	Average	StdDev	95% Conf Inter	
P	14	8	11	11	3.0	4	18	10	8	10	9	1.2	6	12
Ti	28	35	31	31	3.5	23	40	31	35	33	33	2.0	28	38
V	52	60	72	61	10.1	36	86	82	62	30	58	26.2	-7	123
Cr	79	78	80	79	1.0	77	81	87	88	80	85	4.4	74	96
Mn	399	396	470	422	41.9	318	526	370	463	576	470	103.2	213	726
Fe	50628	50488	50195	50437	221.0	49888	50986	50724	50496	50424	50548	156.6	50159	50937
Co	1918	1825	1888	1877	47.5	1759	1995	1974	1807	1818	1866	93.4	1634	2098
Ni	3	4	13	7	5.5	-7	20	7	8	8	8	0.6	6	9
Cu	21	13	11	15	5.3	2	28	15	9	8	11	3.8	1	20
Ge	4	5	9	6	2.6	-1	13	8	10	3	7	3.6	-2	16
Mo	8	14	13	12	3.2	4	20	6	5	13	8	4.4	-3	19
Sn	4	1	2	2	1.5	-1	6	0	1	1	1	0.6	-1	2
Sb	2	3	1	2	1.0	0	4	2	2	1	2	0.6	0	3

Label	2-1A Top	2-1 A Mid	2-1 A Bot					2-1 B Top	2-1 B Mid	2-1 B Bot				
Store	Lowe's							Lowe's						
Brand	LDR China							LDR China						
Location	Masslion, OH							Masslion, OH						
Slice	end							middle						
Spot	top	middle	bottom	Average	StdDev	95% Conf Inter		top	middle	bottom	Average	StdDev	95% Conf Inter	
P	8	12	9	10	2.1	4	15	7	11	10	9	2.1	4	15
Ti	30	39	34	34	4.5	23	46	23	27	28	26	2.6	19	33
V	84	57	48	63	18.7	16	110	71	56	44	57	13.5	23	91
Cr	57	46	66	56	10.0	31	81	56	46	50	51	5.0	38	63
Mn	357	409	391	386	26.4	320	451	377	382	344	368	20.6	316	419
Fe	50641	50668	50244	50518	237.4	49928	51107	50680	50449	51029	50719	292.0	49994	51445
Co	1956	1928	1908	1931	24.1	1871	1991	1797	1934	1900	1877	71.3	1700	2054
Ni	4	8	9	7	2.6	0	14	1	7	5	4	3.1	-3	12
Cu	6	10	11	9	2.6	2	16	9	6	5	7	2.1	1	12
Ge	8	8	3	6	2.9	-1	14	3	7	6	5	2.1	0	11
Mo	11	11	8	10	1.7	6	14	9	11	10	10	1.0	8	12
Sn	1	1	7	3	3.5	-6	12	1	1	5	2	2.3	-3	8
Sb	2	1	1	1	0.6	0	3	1	3	1	2	1.2	-1	5

Label	2-2 A Top	2-2 A Mid	2-2 A Bot					2-2 B Top	2-2 B Mid	2-2 B Bot				
Store	Lowes							Lowes						
Brand	LDR China							LDR China						
Location	Masslion, OH							Masslion, OH						
Slice	end							middle						
Spot	top	middle	bottom	Average	StdDev	95% Conf Inter		top	middle	bottom	Average	StdDev	95% Conf Inter	
P	6	4	7	6	1.5	2	9	5	11	9	8	3.1	1	16
Ti	38	36	24	33	7.6	14	51	39	33	30	34	4.6	23	45
V	46	45	56	49	6.1	34	64	75	58	52	62	11.9	32	91
Cr	162	147	137	149	12.6	117	180	150	168	160	159	9.0	137	182
Mn	361	385	365	370	12.9	338	402	385	368	375	376	8.5	355	397
Fe	51459	50879	50460	50933	501.7	49686	52179	50928	50627	51009	50855	201.3	50355	51355
Co	1939	1897	1916	1917	21.0	1865	1970	1939	1836	1910	1895	53.1	1763	2027
Ni	15	19	21	18	3.1	11	26	15	27	23	22	6.1	6	37
Cu	3	11	10	8	4.4	-3	19	7	5	6	6	1.0	4	8
Ge	5	6	10	7	2.6	0	14	8	1	6	5	3.6	-4	14
Mo	15	10	5	10	5.0	-2	22	15	4	13	11	5.9	-4	25
Sn	1	2	2	2	0.6	0	3	3	4	4	4	0.6	2	5
Sb	1	1	1	1	0.0	1	1	1	2	2	2	0.6	0	3

Label	2-3 A Top	2-3 A Mid	2-3 A Bot					2-3 B Top	2-3 B Mid	2-3 B Bot				
Store	Lowes							Lowes						
Brand	LDR China							LDR China						
Location	Masslion, OH							Masslion, OH						
Slice	end							middle						
Spot	top	middle	bottom	Average	StdDev	95% Conf Inter		top	middle	bottom	Average	StdDev	95% Conf Inter	
P	10	5	13	9	4.0	-1	19	7	7	9	8	1.2	5	11
Ti	16	22	32	23	8.1	3	43	32	22	23	26	5.5	12	39
V	54	80	146	93	47.4	-24	211	47	73	63	61	13.1	28	94
Cr	36	44	60	47	12.2	16	77	41	52	44	46	5.7	32	60
Mn	314	350	360	341	24.2	281	401	349	363	346	353	9.1	330	375
Fe	51006	50470	50528	50668	294.1	49937	51399	50188	50508	51232	50643	534.9	49314	51971
Co	1901	1945	1926	1924	22.1	1869	1979	1946	1847	1876	1890	50.9	1763	2016
Ni	5	5	7	6	1.2	3	9	4	8	8	7	2.3	1	12
Cu	7	8	6	7	1.0	5	9	4	6	6	5	1.2	2	8
Ge	6	7	14	9	4.4	-2	20	8	5	5	6	1.7	2	10
Mo	4	8	13	8	4.5	-3	20	10	10	11	10	0.6	9	12
Sn	2	1	1	1	0.6	0	3	3	1	1	2	1.2	-1	5
Sb	2	1	2	2	0.6	0	3	1	1	2	1	0.6	0	3

Label	3-1 A Top	3-1 A Mid	3-1 A Bot					3-1 B Top	3-1 B Mid	3-1 B Bot				
Store	Home Depot							Home Depot						
Brand	LDR China							LDR China						
Location	Washington, PA							Washington, PA						
Slice	end							middle						
Spot	top	middle	bottom	Average	StdDev	95% Conf Inter		top	middle	bottom	Average	StdDev	95% Conf Inter	
P	6	7	9	7	1.5	4	11	12	9	9	10	1.7	6	14
Ti	22	26	25	24	2.1	19	30	20	34	26	27	7.0	9	44
V	86	66	83	78	10.8	52	105	61	77	58	65	10.2	40	91
Cr	73	57	63	64	8.1	44	84	71	62	66	66	4.5	55	78
Mn	367	379	327	358	27.2	290	425	375	356	401	377	22.6	321	433
Fe	50964	50275	50463	50567	356.2	49683	51452	50633	50641	50716	50663	45.8	50550	50777
Co	1963	1931	1913	1936	25.3	1873	1999	1856	1909	1916	1894	32.8	1812	1975
Ni	11	10	8	10	1.5	6	13	8	10	8	9	1.2	6	12
Cu	11	9	11	10	1.2	7	13	7	5	12	8	3.6	-1	17
Ge	7	6	7	7	0.6	5	8	6	16	10	11	5.0	-2	23
Mo	8	10	8	9	1.2	6	12	14	9	8	10	3.2	2	18
Sn	2	0	1	1	1.0	-1	3	2	3	1	2	1.0	0	4
Sb	3	1	1	2	1.2	-1	5	1	1	1	1	0.0	1	1

Label	3-2 A Top	3-2 A Mid	3-2 A Bot					3-2 B Top	3-2 B Mid	3-2 B Bot				
Store	Home Depot							Home Depot						
Brand	LDR China							LDR China						
Location	Washington, PA							Washington, PA						
Slice	end							middle						
Spot	top	middle	bottom	Average	StdDev	95% Conf Inter		top	middle	bottom	Average	StdDev	95% Conf Inter	
P	6	11	13	10	3.6	1	19	7	9	5	7	2.0	2	12
Ti	36	24	25	28	6.7	12	45	21	25	20	22	2.6	15	29
V	94	61	61	72	19.1	25	119	78	49	63	63	14.5	27	99
Cr	83	68	68	73	8.7	51	95	80	68	66	71	7.6	53	90
Mn	360	481	388	410	63.3	252	567	350	368	347	355	11.4	327	383
Fe	50154	50493	50554	50400	215.5	49865	50936	50711	50659	50563	50644	75.1	50458	50831
Co	1796	1920	1979	1898	93.4	1666	2130	1969	1905	1872	1915	49.3	1793	2038
Ni	5	10	9	8	2.6	1	15	7	7	8	7	0.6	6	9
Cu	7	8	8	8	0.6	6	9	5	9	10	8	2.6	1	15
Ge	9	10	11	10	1.0	8	12	6	3	6	5	1.7	1	9
Mo	6	10	11	9	2.6	2	16	10	4	9	8	3.2	0	16
Sn	0	0	1	0	0.6	-1	2	2	1	1	1	0.6	0	3
Sb	3	1	3	2	1.2	-1	5	0	2	1	1	1.0	-1	3

Label	3-3 A Top	3-3 A Mid	3-3 A Bot					3-3 B Top	3-3 B Mid	3-3 B Bot				
Store	Home Depot							Home Depot						
Brand	LDR China							LDR China						
Location	Washington, PA							Washington, PA						
Slice	end							middle						
Spot	top	middle	bottom	Average	StdDev	95% Conf Inter		top	middle	bottom	Average	StdDev	95% Conf Inter	
P	7	8	5	7	1.5	3	10	7	12	9	9	2.5	3	16
Ti	39	27	27	31	6.9	14	48	29	37	21	29	8.0	9	49
V	59	77	85	74	13.3	41	107	65	71	87	74	11.4	46	103
Cr	66	74	60	67	7.0	49	84	61	62	75	66	7.8	47	85
Mn	379	374	360	371	9.8	347	395	323	358	367	349	23.2	292	407
Fe	50610	50670	50445	50575	116.5	50286	50864	50863	50937	50260	50687	371.4	49764	51609
Co	1876	1840	1862	1859	18.1	1814	1904	1833	1889	1872	1865	28.7	1793	1936
Ni	8	7	9	8	1.0	6	10	7	6	6	6	0.6	5	8
Cu	10	10	14	11	2.3	6	17	10	8	12	10	2.0	5	15
Ge	9	5	8	7	2.1	2	13	6	10	4	7	3.1	-1	14
Mo	10	14	10	11	2.3	6	17	9	6	8	8	1.5	4	11
Sn	5	3	1	3	2.0	-2	8	0	1	0	0	0.6	-1	2
Sb	1	2	3	2	1.0	0	4	1	2	0	1	1.0	-1	3

Label	4-1A Dup 1	4-1A Dup 2	4-1 A Top	4-1 A Mid	4-1 A Bot					4-1B Dup 1	4-1B Dup 2	4-1 B Top	4-1 B Mid	4-1 B Bot				
Store	Lowe's									Lowe's								
Brand	Mueller Pro-line									Mueller Proline								
Location	Washington, PA									Washington, PA								
Slice	end									middle								
Spot	middle	middle	top	middle	bottom	Average	StdDev	95% Conf	Inter	middle	middle	top	middle	bottom	Average	StdDev	95% Conf	Inter
P	6	11	7	10	12	9	2.6	6	12	11	11	8	9	11	10	1.4	8	12
Ti	37	22	21	31	27	28	6.6	19	36	25	25	22	25	22	24	1.6	22	26
V	45	42	67	49	72	55	13.6	38	72	61	72	54	65	74	65	8.2	55	75
Cr	90	87	89	93	85	89	3.0	85	93	100	110	99	90	81	96	11.0	82	110
Mn	351	364	370	379	385	370	13.3	353	386	360	379	367	356	412	375	22.6	347	403
Fe	50365	50442	50540	50955	50315	50523	255.8	50206	50841	50535	50423	50453	51216	50707	50667	326.3	50262	51072
Co	1871	1904	1805	1835	1873	1858	38.2	1810	1905	1920	1881	1900	1866	1794	1872	48.2	1812	1932
Ni	7	10	6	12	7	8	2.5	5	12	7	11	7	11	11	9	2.2	7	12
Cu	11	6	6	10	10	9	2.4	6	12	7	10	8	8	3	7	2.6	4	10
Ge	7	8	5	7	5	6	1.3	5	8	5	7	10	7	6	7	1.9	5	9
Mo	14	9	5	9	16	11	4.4	5	16	4	7	10	14	10	9	3.7	4	14
Sn	2	2	1	3	2	2	0.7	1	3	2	2	3	1	1	2	0.8	1	3
Sb	1	2	2	5	0	2	1.9	0	4	2	1	1	1	0	1	0.7	0	2

Label	4-2 A Top	4-2 A Mid	4-2 A Bot					4-2 B Top	4-2 B Mid	4-2 B Bot				
Store	Lowes							Lowes						
Brand	Mueller Proline							Mueller Proline						
Location	Washington, PA							Washington, PA						
Slice	end							middle						
Spot	top	middle	bottom	Average	StdDev	95% Conf Inter		top	middle	bottom	Average	StdDev	95% Conf Inter	
P	6	7	6	6	0.6	5	8	8	5	3	5	2.5	-1	12
Ti	21	30	29	27	4.9	14	39	34	25	28	29	4.6	18	40
V	111	63	81	85	24.2	25	145	61	132	63	85	40.4	-15	186
Cr	42	59	62	54	10.8	28	81	68	58	74	67	8.1	47	87
Mn	369	339	378	362	20.4	311	413	492	374	363	410	71.5	232	587
Fe	50675	50882	50976	50844	154.0	50462	51227	50653	51236	51074	50988	300.9	50240	51735
Co	1887	1834	1853	1858	26.9	1791	1925	1969	1874	1799	1881	85.2	1669	2092
Ni	6	4	2	4	2.0	-1	9	9	4	4	6	2.9	-2	13
Cu	7	6	7	7	0.6	5	8	2	4	4	3	1.2	0	6
Ge	14	6	9	10	4.0	0	20	9	13	9	10	2.3	5	16
Mo	10	8	6	8	2.0	3	13	9	10	9	9	0.6	8	11
Sn	0	1	3	1	1.5	-2	5	1	1	2	1	0.6	0	3
Sb	4	5	2	4	1.5	0	7	2	0	4	2	2.0	-3	7

Label	4-3 A Top	4-3 A Mid	4-3 A Bot					4-3 B Top	4-3 B Mid	4-3 B Bot				
Store	Lowes							Lowes						
Brand	Mueller Pro-line							Mueller Proline						
Location	Washington, PA							Washington, PA						
Slice	end							middle						
Spot	top	middle	bottom	Average	StdDev	95% Conf Inter		top	middle	bottom	Average	StdDev	95% Conf Inter	
P	9	6	8	8	1.5	4	11	10	3	12	8	4.7	-3	20
Ti	28	23	39	30	8.2	10	50	19	13	18	17	3.2	9	25
V	70	76	145	97	41.7	-7	201	49	80	110	80	30.5	4	155
Cr	57	70	61	63	6.7	46	79	59	57	72	63	8.1	42	83
Mn	371	393	362	375	15.9	336	415	420	370	417	402	28.0	333	472
Fe	50527	50761	50408	50565	179.6	50119	51011	50434	50601	50282	50439	159.6	50043	50835
Co	1848	1815	1911	1858	48.8	1737	1979	1893	1766	1926	1862	84.5	1652	2072
Ni	3	3	2	3	0.6	1	4	3	6	7	5	2.1	0	11
Cu	8	5	7	7	1.5	3	10	5	9	9	8	2.3	2	13
Ge	7	5	19	10	7.6	-8	29	11	8	13	11	2.5	4	17
Mo	3	17	8	9	7.1	-8	27	6	13	12	10	3.8	1	20
Sn	1	4	5	3	2.1	-2	9	3	0	1	1	1.5	-2	5
Sb	1	1	2	1	0.6	0	3	1	1	1	1	0.0	1	1

Label	5-1A Top	5-1 A Mid	5-1 A Bot					5-1 B Top	5-1 B Mid	5-1 B Bot				
Store	Home Depot							Home Depot						
Brand	Mueller B&K							Mueller B&K						
Location	Robinson, PA							Robinson, PA						
Slice	end							middle						
Spot	top	middle	bottom	Average	StdDev	95% Conf Inter		top	middle	bottom	Average	StdDev	95% Conf Inter	
P	13	9	14	12	2.6	5	19	8	11	17	12	4.6	1	23
Ti	62	74	45	60	14.6	24	97	62	61	74	66	7.2	48	84
V	71	64	65	67	3.8	57	76	63	70	70	68	4.0	58	78
Cr	91	89	78	86	7.0	69	103	105	156	142	134	26.4	69	200
Mn	333	353	374	353	20.5	302	404	355	353	336	348	10.4	322	374
Fe	50104	49853	49489	49815	309.2	49047	50583	49125	50060	49150	49445	532.8	48122	50768
Co	1891	1822	1923	1879	51.6	1750	2007	1925	1867	1836	1876	45.2	1764	1988
Ni	26	20	22	23	3.1	15	30	26	34	35	32	4.9	19	44
Cu	29	16	21	22	6.6	6	38	18	13	31	21	9.3	-2	44
Ge	15	18	15	16	1.7	12	20	19	14	30	21	8.2	1	41
Mo	4	7	15	9	5.7	-5	23	8	11	14	11	3.0	4	18
Sn	1	3	2	2	1.0	0	4	2	0	1	1	1.0	-1	3
Sb	1	1	1	1	0.0	1	1	4	0	1	2	2.1	-4	7

Label	5-2 A Top	5-2 A Mid	5-2 A Bot					5-2 B Top	5-2 B Mid	5-2 B Bot				
Store	Home Depot							Home Depot						
Brand	Mueller B&K							Mueller B&K						
Location	Robinson, PA							Robinson, PA						
Slice	end							middle						
Spot	top	middle	bottom	Average	StdDev	95% Conf Inter		top	middle	bottom	Average	StdDev	95% Conf Inter	
P	7	11	8	9	2.1	3	14	11	7	9	9	2.0	4	14
Ti	28	30	23	27	3.6	18	36	30	35	27	31	4.0	21	41
V	61	73	55	63	9.2	40	86	46	76	112	78	33.0	-4	160
Cr	49	83	65	66	17.0	23	108	67	70	68	68	1.5	65	72
Mn	279	284	277	280	3.6	271	289	282	303	259	281	22.0	227	336
Fe	50511	50853	50647	50670	172.2	50243	51098	50412	50735	50687	50611	174.3	50178	51044
Co	1842	1966	1976	1928	74.6	1743	2113	1912	1997	1879	1929	60.9	1778	2081
Ni	5	3	5	4	1.2	1	7	3	3	9	5	3.5	-4	14
Cu	9	10	11	10	1.0	8	12	10	12	11	11	1.0	9	13
Ge	9	11	11	10	1.2	7	13	4	6	6	5	1.2	2	8
Mo	6	10	9	8	2.1	3	14	10	5	9	8	2.6	1	15
Sn	3	0	1	1	1.5	-2	5	2	4	1	2	1.5	-1	6
Sb	2	1	1	1	0.6	0	3	1	2	0	1	1.0	-1	3

Label	5-3 A Top	5-3 A Mid	5-3 A Bot					5-3 B Top	5-3 B Mid	5-3 B Bot				
Store	Home Depot							Home Depot						
Brand	Mueller B&K							Mueller B&K						
Location	Robinson, PA							Robinson, PA						
Slice	end							middle						
Spot	top	middle	bottom	Average	StdDev	95% Conf Inter		top	middle	bottom	Average	StdDev	95% Conf Inter	
P	7	9	10	9	1.5	5	12	11	12	12	12	0.6	10	13
Ti	56	54	52	54	2.0	49	59	70	47	43	53	14.6	17	90
V	76	72	66	71	5.0	59	84	65	63	83	70	11.0	43	98
Cr	66	55	69	63	7.4	45	82	71	75	75	74	2.3	68	79
Mn	313	323	325	320	6.4	304	336	337	326	325	329	6.7	313	346
Fe	49670	49692	50007	49790	188.5	49321	50258	49835	49765	49797	49799	35.0	49712	49886
Co	1949	1857	1898	1901	46.1	1787	2016	1923	1781	1920	1875	81.1	1673	2076
Ni	14	13	16	14	1.5	11	18	18	14	19	17	2.6	10	24
Cu	25	26	20	24	3.2	16	32	19	10	13	14	4.6	3	25
Ge	12	16	17	15	2.6	8	22	19	16	8	14	5.7	0	28
Mo	12	2	9	8	5.1	-5	20	7	8	15	10	4.4	-1	21
Sn	4	2	3	3	1.0	1	5	7	2	3	4	2.6	-3	11
Sb	4	0	3	2	2.1	-3	8	6	2	2	3	2.3	-2	9

Label	6-1 A Top	6-1 A Mid	6-1 A Bot					6-1 B Top	6-1 B Mid	6-1 B Bot				
Store	Lowes							Lowes						
Brand	Mueller Pro-line							Mueller Proline						
Location	Robinson, PA							Robinson, PA						
Slice	end							middle						
Spot	top	middle	bottom	Average	StdDev	95% Conf Inter		top	middle	bottom	Average	StdDev	95% Conf Inter	
P	7	10	8	8	1.5	5	12	9	12	9	10	1.7	6	14
Ti	27	32	32	30	2.9	23	38	27	46	24	32	11.9	3	62
V	65	83	93	80	14.2	45	116	63	58	55	59	4.0	49	69
Cr	58	55	53	55	2.5	49	62	55	46	58	53	6.2	37	69
Mn	318	278	316	304	22.5	248	360	316	322	316	318	3.5	309	327
Fe	50807	50777	51066	50883	158.9	50489	51278	50599	50659	50831	50696	120.4	50397	50995
Co	1910	1913	1941	1921	17.1	1879	1964	1858	1925	1856	1880	39.3	1782	1977
Ni	7	8	4	6	2.1	1	12	7	10	5	7	2.5	1	14
Cu	13	6	5	8	4.4	-3	19	9	4	9	7	2.9	0	15
Ge	7	12	13	11	3.2	3	19	13	9	4	9	4.5	-3	20
Mo	8	7	6	7	1.0	5	9	16	7	9	11	4.7	-1	22
Sn	2	1	2	2	0.6	0	3	4	0	2	2	2.0	-3	7
Sb	3	1	2	2	1.0	0	4	1	1	3	2	1.2	-1	5

Label	6-2 A Top	6-2 A Mid	6-2 A Bot					6-2 B Top	6-2 B Mid	6-2 B Bot				
Store	Lowes							Lowes						
Brand	Mueller Proline							Mueller Proline						
Location	Robinson, PA							Robinson, PA						
Slice	end							middle						
Spot	top	middle	bottom	Average	StdDev	95% Conf Inter		top	middle	bottom	Average	StdDev	95% Conf Inter	
P	9	7	8	8	1.0	6	10	8	5	6	6	1.5	3	10
Ti	25	24	45	31	11.8	2	61	28	27	28	28	0.6	26	29
V	93	94	69	85	14.2	50	120	66	65	49	60	9.5	36	84
Cr	158	141	129	143	14.6	106	179	147	158	156	154	5.9	139	168
Mn	330	365	349	348	17.5	304	392	366	355	375	365	10.0	340	390
Fe	50556	50509	49872	50312	382.1	49363	51261	50715	50522	50535	50591	107.9	50323	50859
Co	1829	1869	1960	1886	67.1	1719	2053	1913	1893	1848	1885	33.3	1802	1967
Ni	18	9	12	13	4.6	2	24	11	10	11	11	0.6	9	12
Cu	14	12	7	11	3.6	2	20	8	4	7	6	2.1	1	12
Ge	11	8	6	8	2.5	2	15	5	8	11	8	3.0	1	15
Mo	6	2	7	5	2.6	-2	12	8	14	9	10	3.2	2	18
Sn	0	1	2	1	1.0	-1	3	2	3	2	2	0.6	1	4
Sb	2	3	1	2	1.0	0	4	0	1	0	0	0.6	-1	2

Label	6-3 A Top	6-3 A Mid	6-3 A Bot					6-3 B Top	6-3 B Mid	6-3 B Bot				
Store	Lowe's							Lowe's						
Brand	Mueller Pro-line							Mueller Proline						
Location	Robinson, PA							Robinson, PA						
Slice	end							middle						
Spot	top	middle	bottom	Average	StdDev	95% Conf Inter		top	middle	bottom	Average	StdDev	95% Conf Inter	
P	7	9	7	8	1.2	5	11	11	6	7	8	2.6	1	15
Ti	20	27	21	23	3.8	13	32	27	36	28	30	4.9	18	43
V	76	74	123	91	27.7	22	160	96	79	80	85	9.5	61	109
Cr	158	187	149	165	19.9	115	214	140	152	178	157	19.4	108	205
Mn	364	345	371	360	13.5	327	393	376	356	399	377	21.5	324	430
Fe	50349	50773	49935	50352	419.0	49311	51393	50784	50820	50642	50749	94.1	50515	50982
Co	1811	1772	1960	1848	99.2	1601	2094	1928	1886	1841	1885	43.5	1777	1993
Ni	9	11	11	10	1.2	7	13	17	14	14	15	1.7	11	19
Cu	10	5	7	7	2.5	1	14	7	10	9	9	1.5	5	12
Ge	11	7	12	10	2.6	3	17	3	7	6	5	2.1	0	11
Mo	5	6	8	6	1.5	3	10	6	6	8	7	1.2	4	10
Sn	0	2	1	1	1.0	-1	3	3	4	1	3	1.5	-1	6
Sb	0	4	1	2	2.1	-4	7	1	2	2	2	0.6	0	3

Label	7-1 A Top	7-1 A Mid	7-1 A Bot					7-1 B Top	7-1 B Mid	7-1 B Bot				
Store	Lowes							Lowes						
Brand	Mueller Proline							Mueller Proline						
Location	Wheeling, WV							Wheeling, WV						
Slice	end							middle						
Spot	top	middle	bottom	Average	StdDev	95% Conf Inter		top	middle	bottom	Average	StdDev	95% Conf Inter	
P	8	8	6	7	1.2	4	10	6	5	19	10	7.8	-9	29
Ti	21	30	27	26	4.6	15	37	36	30	24	30	6.0	15	45
V	68	83	69	73	8.4	53	94	64	100	47	70	27.1	3	138
Cr	99	90	114	101	12.1	71	131	91	95	91	92	2.3	87	98
Mn	334	382	402	373	34.9	286	459	311	307	359	326	28.9	254	398
Fe	50736	50497	50317	50517	210.2	49995	51039	50649	50419	50766	50611	176.5	50173	51050
Co	1930	1868	1860	1886	38.3	1791	1981	1952	1968	1846	1922	66.3	1757	2087
Ni	3	7	11	7	4.0	-3	17	10	5	7	7	2.5	1	14
Cu	10	10	4	8	3.5	-1	17	13	7	14	11	3.8	2	21
Ge	6	10	8	8	2.0	3	13	6	12	9	9	3.0	2	16
Mo	8	9	9	9	0.6	7	10	8	6	4	6	2.0	1	11
Sn	1	5	3	3	2.0	-2	8	1	1	3	2	1.2	-1	5
Sb	3	1	2	2	1.0	0	4	0	1	1	1	0.6	-1	2

Label	7-2 A Top	7-2 A Mid	7-2 A Bot					7-2 B Top	7-2 B Mid	7-2 B Bot				
Store	Lowes							Lowes						
Brand	Mueller Pro-line							Mueller Proline						
Location	Wheeling, WV							Wheeling, WV						
Slice	end							middle						
Spot	top	middle	bottom	Average	StdDev	95% Conf Inter		top	middle	bottom	Average	StdDev	95% Conf Inter	
P	11	11	7	10	2.3	4	15	8	4	12	8	4.0	-1.9	17.9
Ti	32	41	22	32	9.5	8	55	35	19	37	30	9.9	5.8	54.8
V	86	116	82	95	18.6	49	141	66	52	81	66	14.5	30.3	102.4
Cr	76	102	84	87	13.3	54	120	100	87	89	92	7.0	74.6	109.4
Mn	370	399	382	384	14.6	347	420	340	326	379	348	27.5	280.1	416.6
Fe	50233	50273	50420	50309	98.5	50064	50553	50287	50708	50867	50621	299.7	49876.2	51365.2
Co	1877	1792	1816	1828	43.8	1719	1937	1850	1963	1843	1885	67.4	1718.0	2052.6
Ni	6	8	7	7	1.0	5	9	9	8	8	8	0.6	6.9	9.8
Cu	8	7	9	8	1.0	6	10	8	8	9	8	0.6	6.9	9.8
Ge	11	9	3	8	4.2	-3	18	6	5	10	7	2.6	0.4	13.6
Mo	10	6	12	9	3.1	2	17	3	6	13	7	5.1	-5.4	20.1
Sn	4	3	1	3	1.5	-1	6	2	2	2	2	0.0	2.0	2.0
Sb	7	2	2	4	2.9	-4	11	3	3	4	3	0.6	1.9	4.8

Label	7-3 A Top	7-3 A Mid	7-3 A Bot					7-3 B Top	7-3 B Mid	7-3 B Bot				
Store	Lowes							Lowes						
Brand	Mueller Proline							Mueller Proline						
Location	Wheeling, WV							Wheeling, WV						
Slice	end							middle						
Spot	top	middle	bottom	Average	StdDev	95% Conf Inter		top	middle	bottom	Average	StdDev	95% Conf Inter	
P	7	12	4	8	4.0	-2	18	15	16	9	13	3.8	4	23
Ti	29	22	24	25	3.6	16	34	25	30	33	29	4.0	19	39
V	50	63	99	71	25.4	8	134	67	58	131	85	39.8	-14	184
Cr	69	52	85	69	16.5	28	110	62	71	73	69	5.9	54	83
Mn	245	286	262	264	20.6	213	316	256	226	278	253	26.1	188	318
Fe	50444	50725	50476	50548	153.8	50166	50930	50642	50701	50998	50780	190.8	50306	51254
Co	1854	1835	1838	1842	10.2	1817	1868	1849	1826	1880	1852	27.1	1784	1919
Ni	7	13	4	8	4.6	-3	19	11	7	9	9	2.0	4	14
Cu	14	17	9	13	4.0	3	23	16	11	10	12	3.2	4	20
Ge	9	8	13	10	2.6	3	17	9	7	20	12	7.0	-5	29
Mo	6	10	17	11	5.6	-3	25	6	8	12	9	3.1	1	16
Sn	1	2	0	1	1.0	-1	3	1	5	2	3	2.1	-3	8
Sb	2	1	3	2	1.0	0	4	4	4	3	4	0.6	2	5

Label	8-1 A Top	8-1 A Mid	8-1 A Bot					8-1 B Top	8-1 B Mid	8-1 B Bot				
Store	Northern Panhandle							Northern Panhandle						
Brand	Wheaton							Wheaton						
Location	Wheeling, WV							Wheeling, WV						
Slice	end							middle						
Spot	top	middle	bottom	Average	StdDev	95% Conf Inter		top	middle	bottom	Average	StdDev	95% Conf Inter	
P	14	9	6	10	4.0	0	20	11	10	11	11	0.6	9	12
Ti	25	33	31	30	4.2	19	40	25	32	32	30	4.0	20	40
V	78	47	66	64	15.6	25	102	59	73	37	56	18.1	11	101
Cr	81	76	77	78	2.6	71	85	75	56	62	64	9.7	40	88
Mn	369	340	405	371	32.6	290	452	332	357	398	362	33.3	280	445
Fe	50637	50570	50488	50565	74.6	50380	50750	50374	50321	50805	50500	265.5	49841	51159
Co	1847	1996	1808	1884	99.2	1637	2130	1990	1721	1808	1840	137.3	1499	2181
Ni	8	5	7	7	1.5	3	10	7	3	4	5	2.1	-1	10
Cu	13	9	14	12	2.6	5	19	12	12	16	13	2.3	8	19
Ge	7	7	5	6	1.2	3	9	6	10	7	8	2.1	2	13
Mo	8	9	5	7	2.1	2	13	9	16	6	10	5.1	-2	23
Sn	1	2	1	1	0.6	0	3	3	2	4	3	1.0	1	5
Sb	1	1	2	1	0.6	0	3	3	2	2	2	0.6	1	4

Label	8-2 A Top	8-2 A Mid	8-2 A Bot					8-2 B Top	8-2 B Mid	8-2 B Bot				
Store	Northern Panhandle							Northern Panhandle						
Brand	China							China						
Location	Wheeling, WV							Wheeling, WV						
Slice	end							middle						
Spot	top	middle	bottom	Average	StdDev	95% Conf Inter		top	middle	bottom	Average	StdDev	95% Conf Inter	
P	12	7	12	10	2.9	3	18	7	5	7	6	1.2	3	9
Ti	28	25	31	28	3.0	21	35	33	23	41	32	9.0	10	55
V	120	82	70	91	26.1	26	156	67	63	52	61	7.8	41	80
Cr	68	68	55	64	7.5	45	82	59	54	59	57	2.9	50	65
Mn	249	307	289	282	29.7	208	355	305	267	252	275	27.3	207	343
Fe	50629	50558	50647	50611	47.1	50494	50728	50889	50569	50864	50774	178.0	50332	51216
Co	1829	1882	1804	1838	39.8	1739	1937	1762	1999	1835	1865	121.4	1564	2167
Ni	11	10	6	9	2.6	2	16	13	11	16	13	2.5	7	20
Cu	22	20	29	24	4.7	12	35	18	19	21	19	1.5	16	23
Ge	13	9	8	10	2.6	3	17	9	7	10	9	1.5	5	12
Mo	10	6	8	8	2.0	3	13	7	12	6	8	3.2	0	16
Sn	4	2	1	2	1.5	-1	6	3	2	4	3	1.0	1	5
Sb	4	3	3	3	0.6	2	5	1	0	2	1	1.0	-1	3

Label	8-3 A Dup 1	8-3A Dup 2	8-3 A Top	8-3 A Mid	8-3 A Bot					8-3B Dup 1	8-3B Dup2	8-3 B Top	8-3 B Mid	8-3 B Bot				
Store	Northern Panhandle									Northern Panhandle								
Brand	Ukraine									Ukraine								
Location	Wheeling, WV									Wheeling, WV								
Slice	end									middle								
Spot	middle	middle	top	middle	bottom	Average	StdDev	95% Conf	Inter	middle	middle	top	middle	bottom	Average	StdDev	95% Conf	Inter
P	9	9	14	8	9	10	2.4	7	13	6	17	7	12	10	10	4.4	5	16
Ti	26	25	32	32	27	28	3.4	24	33	35	23	18	31	37	29	8.1	19	39
V	40	49	43	55	109	59	28.4	24	94	89	100	99	99	113	100	8.5	89	111
Cr	112	107	88	75	92	95	14.9	76	113	95	77	98	98	92	92	8.7	81	103
Mn	321	291	324	294	264	299	24.6	268	329	313	270	288	331	327	306	26.1	273	338
Fe	50699	50696	50039	49844	50060	50268	401.4	49769	50766	50559	50793	50422	50445	50230	50490	206.7	50233	50746
Co	1884	1823	1915	1974	1915	1902	55.0	1834	1970	1948	2042	1921	2001	1978	1978	46.8	1920	2036
Ni	13	7	10	13	19	12	4.4	7	18	14	8	10	7	11	10	2.7	7	13
Cu	25	28	19	27	33	26	5.1	20	33	31	25	21	27	23	25	3.8	21	30
Ge	6	3	6	9	12	7	3.4	3	11	9	8	12	5	9	9	2.5	5	12
Mo	9	7	11	8	11	9	1.8	7	11	9	10	11	10	13	11	1.5	9	12
Sn	2	2	4	3	0	2	1.5	0	4	1	3	3	1	1	2	1.1	0	3
Sb	5	1	0	1	4	2	2.2	0	5	4	2	0	1	2	2	1.5	0	4

Label	9-1A Top	9-1 A Mid	9-1 A Bot					9-1 B Top	9-1 B Mid	9-1 B Bot				
Store	Lowes							Lowes						
Brand	Mueller Proline							Mueller Proline						
Location	Morgantown, WV							Morgantown, WV						
Slice	end							middle						
Spot	top	middle	bottom	Average	StdDev	95% Conf Inter		top	middle	bottom	Average	StdDev	95% Conf Inter	
P	6	5	9	7	2.1	1	12	8	10	3	7	3.6	-2	16
Ti	30	37	28	32	4.7	20	43	33	31	35	33	2.0	28	38
V	45	69	47	54	13.3	21	87	50	73	83	69	16.9	27	111
Cr	62	45	58	55	8.9	33	77	65	51	69	62	9.5	38	85
Mn	275	268	323	289	29.9	214	363	317	288	310	305	15.1	267	343
Fe	51202	50417	50222	50614	518.8	49325	51902	51151	50962	50927	51013	120.5	50714	51313
Co	1833	1850	1829	1837	11.2	1810	1865	1939	1995	1767	1900	118.8	1605	2195
Ni	4	4	2	3	1.2	0	6	4	4	6	5	1.2	2	8
Cu	11	7	8	9	2.1	3	14	5	7	9	7	2.0	2	12
Ge	3	12	7	7	4.5	-4	19	6	6	6	6	0.0	6	6
Mo	14	9	13	12	2.6	5	19	13	12	9	11	2.1	6	17
Sn	0	2	1	1	1.0	-1	3	3	0	1	1	1.5	-2	5
Sb	2	3	1	2	1.0	0	4	1	2	2	2	0.6	0	3

Label	9-2 A Top	9-2 A Mid	9-2 A Bot					9-2 B Top	9-2 B Mid	9-2 B Bot				
Store	Lowes							Lowes						
Brand	Mueller Proline							Mueller Proline						
Location	Morgantown, WV							Morgantown, WV						
Slice	end							middle						
Spot	top	middle	bottom	Average	StdDev	95% Conf Inter		top	middle	bottom	Average	StdDev	95% Conf Inter	
P	7	5	2	5	2.5	-2	11	9	7	5	7	2.0	2	12
Ti	34	27	35	32	4.4	21	43	14	30	42	29	14.0	-6	64
V	61	37	79	59	21.1	7	111	75	97	60	77	18.6	31	124
Cr	45	70	61	59	12.7	27	90	60	73	56	63	8.9	41	85
Mn	279	347	348	325	39.6	226	423	317	279	268	288	25.7	224	352
Fe	50465	50578	50646	50563	91.4	50336	50790	50550	50483	50888	50640	217.1	50101	51180
Co	1974	1855	1850	1893	70.2	1719	2067	2055	1879	1912	1949	93.6	1716	2181
Ni	12	1	8	7	5.6	-7	21	7	7	5	6	1.2	3	9
Cu	7	8	10	8	1.5	5	12	10	7	10	9	1.7	5	13
Ge	7	2	7	5	2.9	-2	13	12	11	8	10	2.1	5	16
Mo	9	8	6	8	1.5	4	11	9	10	10	10	0.6	8	11
Sn	1	2	2	2	0.6	0	3	0	2	1	1	1.0	-1	3
Sb	3	0	2	2	1.5	-2	5	0	3	2	2	1.5	-2	5

Label	9-3 A Top	9-3 A Mid	9-3 A Bot					9-3 B Top	9-3 B Mid	9-3 B Bot				
Store	Lowes							Lowes						
Brand	Mueller Proline							Mueller Proline						
Location	Morgantown, WV							Morgantown, WV						
Slice	end							middle						
Spot	top	middle	bottom	Average	StdDev	95% Conf Inter		top	middle	bottom	Average	StdDev	95% Conf Inter	
P	2	6	10	6	4.0	-4	16	8	4	5	6	2.1	0	11
Ti	27	34	31	31	3.5	22	39	27	26	34	29	4.4	18	40
V	60	51	100	70	26.1	6	135	46	114	137	99	47.3	-19	217
Cr	99	93	100	97	3.8	88	107	73	88	98	86	12.6	55	118
Mn	307	339	347	331	21.2	278	384	314	408	404	375	53.2	243	507
Fe	50826	50897	50572	50765	170.9	50341	51189	50437	50369	51033	50613	365.3	49706	51520
Co	1782	1790	1989	1854	117.3	1562	2145	1905	1933	1926	1921	14.6	1885	1958
Ni	10	11	4	8	3.8	-1	18	8	8	8	8	0.0	8	8
Cu	12	11	9	11	1.5	7	14	9	8	7	8	1.0	6	10
Ge	5	8	4	6	2.1	0	11	7	13	10	10	3.0	3	17
Mo	9	7	13	10	3.1	2	17	8	7	14	10	3.8	0	19
Sn	0	2	1	1	1.0	-1	3	2	0	1	1	1.0	-1	3
Sb	2	0	1	1	1.0	-1	3	2	1	1	1	0.6	0	3

Label	10-1 A Top	10-1 A Mid	10-1 A Bot					10-1 B Top	10-1 B Mid	10-1 B Bot				
Store	Ace							Ace						
Brand	Wheatland							Wheatland						
Location	Morgantown, WV							Morgantown, WV						
Slice	end							middle						
Spot	top	middle	bottom	Average	StdDev	95% Conf Inter		top	middle	bottom	Average	StdDev	95% Conf Inter	
P	7	8	8	8	0.6	6	9	6	4	7	6	1.5	2	9
Ti	39	38	18	32	11.8	2	61	28	29	31	29	1.5	26	33
V	49	53	57	53	4.0	43	63	47	27	118	64	47.8	-55	183
Cr	79	90	86	85	5.6	71	99	63	79	76	73	8.5	52	94
Mn	797	344	315	485	270.3	-186	1157	376	397	314	362	43.2	255	470
Fe	49949	51009	50187	50382	556.2	49000	51763	50362	50695	50560	50539	167.5	50123	50955
Co	1792	1861	1889	1847	49.9	1723	1971	1869	1870	1875	1871	3.2	1863	1879
Ni	5	7	8	7	1.5	3	10	4	6	10	7	3.1	-1	14
Cu	11	12	9	11	1.5	7	14	9	15	5	10	5.0	-3	22
Ge	9	3	8	7	3.2	-1	15	3	6	8	6	2.5	-1	12
Mo	10	21	9	13	6.7	-3	30	9	13	13	12	2.3	6	17
Sn	2	4	1	2	1.5	-1	6	0	2	2	1	1.2	-2	4
Sb	2	4	1	2	1.5	-1	6	0	2	2	1	1.2	-2	4

Label	10-2A Dup 1	10-2A Dup 2	10-2 A Top	10-2 A Mid	10-2 A Bot					10-2B Dup 1	10-2B Dup 2	10-2 B Top	10-2 B Mid	10-2 B Bot				
Store	Ace									Ace								
Brand	Anvil									Anvil								
Location	Morgantown, WV									Morgantown, WV								
Slice	end									middle								
Spot	middle	middle	top	middle	bottom	Average	StdDev	95% Conf	Inter	middle	middle	top	middle	bottom	Average	StdDev	95% Conf	Inter
P	6	7	7	13	6	8	2.9	4	11	9	10	13	9	9	10	1.7	8	12
Ti	27	26	29	28	24	27	1.9	24	29	27	28	36	26	36	31	5.0	24	37
V	69	45	52	57	119	68	29.6	32	105	67	70	58	97	40	66	20.7	41	92
Cr	84	92	73	95	91	87	8.8	76	98	85	87	102	73	86	87	10.3	74	99
Mn	436	425	373	400	384	404	26.7	371	437	423	394	443	386	364	402	31.2	363	441
Fe	50541	50178	50468	50574	50212	50395	186.6	50163	50626	50841	50706	50171	50631	50264	50523	290.4	50162	50883
Co	1876	1874	1947	1953	2089	1948	87.4	1839	2056	1839	1856	1944	2056	1921	1923	86.1	1816	2030
Ni	2	5	11	4	5	5	3.4	1	10	6	3	13	9	8	8	3.7	3	12
Cu	16	19	14	11	17	15	3.0	12	19	13	12	8	10	19	12	4.2	7	18
Ge	4	12	7	8	10	8	3.0	4	12	16	11	10	10	6	11	3.6	6	15
Mo	9	8	9	9	5	8	1.7	6	10	12	9	8	13	9	10	2.2	8	13
Sn	6	1	1	2	2	2	2.1	0	5	2	3	2	2	1	2	0.7	1	3
Sb	2	1	0	4	1	2	1.5	0	3	0	4	1	1	1	1	1.5	0	3

Label	10-3 A Top	10-3 A Mid	10-3 A Bot					10-3 B Top	10-3 B Mid	10-3 B Bot				
Store	Ace							Ace						
Brand	Anvil							Anvil						
Location	Morgantown, WV							Morgantown, WV						
Slice	end							middle						
Spot	top	middle	bottom	Average	StdDev	95% Conf Inter		top	middle	bottom	Average	StdDev	95% Conf Inter	
P	10.0000	7	10	9	1.7	5	13	8	7	7	7	0.6	6	9
Ti	31.0000	34	37	34	3.0	27	41	31	24	35	30	5.6	16	44
V	33.0000	23	60	39	19.1	-9	86	27	38	161	75	74.4	-109	260
Cr	90.0000	94	96	93	3.1	86	101	77	80	79	79	1.5	75	82
Mn	411.0000	396	423	410	13.5	376	444	412	348	423	394	40.5	294	495
Fe	50585.0000	50972	50695	50751	199.4	50255	51246	50900	51241	50907	51016	194.9	50532	51500
Co	2014.0000	1975	1820	1936	102.6	1681	2191	1924	1859	1877	1887	33.6	1803	1970
Ni	3.0000	7	9	6	3.1	-1	14	3	6	3	4	1.7	0	8
Cu	9.0000	17	10	12	4.4	1	23	14	11	12	12	1.5	9	16
Ge	7.0000	7	9	8	1.2	5	11	3	12	18	11	7.5	-8	30
Mo	6.0000	5	18	10	7.2	-8	28	10	11	8	10	1.5	6	13
Sn	2.0000	4	1	2	1.5	-1	6	4	3	1	3	1.5	-1	6
Sb	1.0000	2	2	2	0.6	0	3	3	1	2	2	1.0	0	4

Label	11-1 A Top	11-1 A Mid	11-1 A Bot					11-1 B Top	11-1 B Mid	11-1 B Bot				
Store	Home Depot							Home Depot						
Brand	Mueller B&K							Mueller B&K						
Location	Cleveland,Oh							Cleveland,Oh						
Slice	end							middle						
Spot	top	middle	bottom	Average	StdDev	95% Conf Inter		top	middle	bottom	Average	StdDev	95% Conf Inter	
P	8	10	9	9	1.0	7	11	13	12	11	12	1.0	10	14
Ti	23	27	35	28	6.1	13	44	27	30	28	28	1.5	25	32
V	50	61	85	65	17.9	21	110	134	53	95	94	40.5	-7	195
Cr	116	105	104	108	6.7	92	125	118	97	112	109	10.8	82	136
Mn	213	227	246	229	16.6	188	270	237	214	220	224	11.9	194	253
Fe	50353	50692	50494	50513	170.3	50090	50936	50388	50337	50895	50540	308.5	49774	51306
Co	1702	1662	1611	1658	45.6	1545	1772	1700	1568	1562	1610	78.0	1416	1804
Ni	9	6	7	7	1.5	4	11	8	12	13	11	2.6	4	18
Cu	6	8	5	6	1.5	3	10	6	13	11	10	3.6	1	19
Ge	7	6	10	8	2.1	2	13	13	10	4	9	4.6	-2	20
Mo	6	8	8	7	1.2	4	10	9	5	4	6	2.6	-1	13
Sn	1	1	3	2	1.2	-1	5	1	3	0	1	1.5	-2	5
Sb	1	0	2	1	1.0	-1	3	2	2	2	2	0.0	2	2

Label	11-2 A Top	11-2 A Mid	11-2 A Bot					11-2 B Top	11-2 B Mid	11-2 B Bot				
Store	Home Depot							Home Depot						
Brand	Mueller B&K							Mueller B&K						
Location	Cleveland,Oh							Cleveland,Oh						
Slice	end							middle						
Spot	top	middle	bottom	Average	StdDev	95% Conf Inter		top	middle	bottom	Average	StdDev	95% Conf Inter	
P	4	9	3	5	3.2	-3	13	13	12	8	11	2.6	4	18
Ti	30	29	26	28	2.1	23	34	24	27	33	28	4.6	17	39
V	82	68	101	84	16.6	43	125	86	55	55	65	17.9	21	110
Cr	102	120	141	121	19.5	73	169	102	95	126	108	16.3	67	148
Mn	227	232	230	230	2.5	223	236	280	304	235	273	35.0	186	360
Fe	50724	50586	50697	50669	73.1	50487	50851	51028	50886	50570	50828	234.4	50246	51410
Co	1603	1576	1632	1604	28.0	1534	1673	1749	1992	1999	1913	142.4	1560	2267
Ni	10	7	10	9	1.7	5	13	11	6	7	8	2.6	1	15
Cu	5	13	7	8	4.2	-2	19	9	7	7	8	1.2	5	11
Ge	9	6	9	8	1.7	4	12	6	6	7	6	0.6	5	8
Mo	9	6	6	7	1.7	3	11	15	8	11	11	3.5	3	20
Sn	2	2	3	2	0.6	1	4	2	1	1	1	0.6	0	3
Sb	2	2	1	2	0.6	0	3	2	3	0	2	1.5	-2	5

Label	11-3 A Top	11-3 A Mid	11-3 A Bot					11-3 B Top	11-3 B Mid	11-3 B Bot				
Store	Home Depot							Home Depot						
Brand	Mueller B&K							Mueller B&K						
Location	Cleveland,Oh							Cleveland,Oh						
Slice	end							middle						
Spot	top	middle	bottom	Average	StdDev	95% Conf Inter		top	middle	bottom	Average	StdDev	95% Conf Inter	
P	8	7	7	7	0.6	6	9	6	11	12	10	3.2	2	18
Ti	33	39	37	36	3.1	29	44	23	34	30	29	5.6	15	43
V	79	95	80	85	9.0	62	107	57	69	61	62	6.1	47	78
Cr	101	107	103	104	3.1	96	111	82	114	106	101	16.7	59	142
Mn	213	251	225	230	19.4	181	278	216	242	296	251	40.8	150	353
Fe	50818	51063	50792	50891	149.5	50520	51262	50952	51177	50776	50968	201.0	50469	51468
Co	1914	2126	1814	1951	159.3	1556	2347	1854	1866	2070	1930	121.4	1628	2232
Ni	8	4	5	6	2.1	0	11	8	5	8	7	1.7	3	11
Cu	7	7	6	7	0.6	5	8	7	9	8	8	1.0	6	10
Ge	6	12	10	9	3.1	2	17	7	9	9	8	1.2	5	11
Mo	14	12	5	10	4.7	-1	22	6	4	14	8	5.3	-5	21
Sn	3	2	2	2	0.6	1	4	4	1	1	2	1.7	-2	6
Sb	2	1	2	2	0.6	0	3	3	1	4	3	1.5	-1	6

Label	12-1 A Top	12-1 A Mid	12-1 A Bot					12-1 B Top	12-1 B Mid	12-1 B Bot				
Store	Lowe's							Lowe's						
Brand	Mueller Proline							Mueller Proline						
Location	Cleveland, Oh							Cleveland, Oh						
Slice	end							middle						
Spot	top	middle	bottom	Average	StdDev	95% Conf Inter		top	middle	bottom	Average	StdDev	95% Conf Inter	
P	7	10	12	10	2.5	3	16	3	9	8	7	3.2	-1	15
Ti	29	25	27	27	2.0	22	32	33	40	34	36	3.8	26	45
V	83	82	94	86	6.7	70	103	89	68	42	66	23.5	8	125
Cr	60	54	53	56	3.8	46	65	65	74	55	65	9.5	41	88
Mn	345	294	251	297	47.1	180	414	304	265	363	311	49.3	188	433
Fe	50504	50998	50873	50792	256.8	50154	51430	50048	50366	49230	49881	586.1	48425	51337
Co	1918	1861	1923	1901	34.4	1815	1986	1942	1932	1962	1945	15.3	1907	1983
Ni	9	2	12	8	5.1	-5	20	8	9	12	10	2.1	4	15
Cu	11	5	13	10	4.2	-1	20	8	16	7	10	4.9	-2	23
Ge	13	6	21	13	7.5	-5	32	6	6	9	7	1.7	3	11
Mo	13	7	10	10	3.0	3	17	6	6	9	7	1.7	3	11
Sn	1	1	2	1	0.6	0	3	1	4	0	2	2.1	-4	7
Sb	1	1	1	1	0.0	1	1	1	0	1	1	0.6	-1	2

Label	12-2 A Top	12-2 A Mid	12-2 A Bot					12-2 B Top	12-2 B Mid	12-2 B Bot				
Store	Lowes							Lowes						
Brand	Mueller Proline							Mueller Proline						
Location	Cleveland,Oh							Cleveland,Oh						
Slice	end							middle						
Spot	top	middle	bottom	Average	StdDev	95% Conf Inter		top	middle	bottom	Average	StdDev	95% Conf Inter	
P	8	9	11	9	1.5	6	13	13	7	9	10	3.1	2	17
Ti	27	26	31	28	2.6	21	35	26	26	28	27	1.2	24	30
V	50	127	65	81	40.8	-21	182	79	54	59	64	13.2	31	97
Cr	67	81	68	72	7.8	53	91	77	72	65	71	6.0	56	86
Mn	376	302	294	324	45.2	212	436	324	367	304	332	32.2	252	412
Fe	51057	50827	50733	50872	166.7	50458	51286	50903	50701	50658	50754	130.8	50429	51079
Co	1892	1952	1935	1926	30.9	1850	2003	1906	1908	1869	1894	22.0	1840	1949
Ni	8	11	11	10	1.7	6	14	7	8	6	7	1.0	5	9
Cu	10	7	8	8	1.5	5	12	9	8	8	8	0.6	7	10
Ge	8	14	10	11	3.1	3	18	4	4	6	5	1.2	2	8
Mo	6	14	9	10	4.0	0	20	5	4	8	6	2.1	0	11
Sn	1	1	3	2	1.2	-1	5	3	0	1	1	1.5	-2	5
Sb	3	3	1	2	1.2	-1	5	0	1	1	1	0.6	-1	2

Label	12-3 A Top	12-3 A Mid	12-3 A Bot					12-3 B Top	12-3 B Mid	12-3 B Bot				
Store	Lowes							Lowes						
Brand	Mueller Proline							Mueller Proline						
Location	Cleveland,Oh							Cleveland,Oh						
Slice	end							middle						
Spot	top	middle	bottom	Average	StdDev	95% Conf Inter		top	middle	bottom	Average	StdDev	95% Conf Inter	
P	6	4	3	4	1.5	1	8	6	7	8	7	1.0	5	9
Ti	26	33	28	29	3.6	20	38	24	31	30	28	3.8	19	38
V	65	94	61	73	18.0	29	118	49	59	68	59	9.5	35	82
Cr	58	62	64	61	3.1	54	69	60	60	70	63	5.8	49	78
Mn	372	351	289	337	43.2	230	445	312	301	311	308	6.1	293	323
Fe	50600	50701	50732	50678	69.0	50506	50849	51208	50716	50758	50894	272.7	50216	51572
Co	1904	1969	1835	1903	67.0	1736	2069	1782	1968	1880	1877	93.0	1646	2108
Ni	8	7	11	9	2.1	3	14	8	4	3	5	2.6	-2	12
Cu	3	5	8	5	2.5	-1	12	15	9	10	11	3.2	3	19
Ge	7	9	9	8	1.2	5	11	5	11	8	8	3.0	1	15
Mo	7	5	8	7	1.5	3	10	15	13	8	12	3.6	3	21
Sn	2	3	1	2	1.0	0	4	2	3	1	2	1.0	0	4
Sb	1	1	3	2	1.2	-1	5	1	3	2	2	1.0	0	4

Label	13-1A Dup 1	13-A Dup 2	13-1 A Top	13-1 A Mid	13-1 A Bot						13-1B Dup 1	13-1 Dup 2	13-1 B Top	13-1 B Mid	13-1 B Bot				
Store	McKean										McKean								
Brand	Wheaton										Wheaton								
Location	Washington, PA										Washington, PA								
Slice	end										middle								
Spot	middle	middle	top	middle	bottom	Average	StdDev	95% Conf Inter		middle	middle	top	middle	bottom	Average	StdDev	95% Conf Inter		
P	8	6	5	3	4	5	1.9	3	8	10	9	11	6	11	9	2.1	7	12	
Ti	28	35	29	34	25	30	4.2	25	35	34	29	27	42	22	31	7.6	21	40	
V	55	50	63	129	34	66	36.7	21	112	52	56	35	453	27	125	184.0	-104	353	
Cr	77	79	71	90	55	74	12.8	58	90	74	62	68	75	71	70	5.2	63	77	
Mn	403	394	398	346	345	377	29.1	341	413	372	389	406	361	378	381	17.2	360	403	
Fe	50848	50567	50676	50519	51485	50819	393.2	50331	51307	50598	50771	50843	50400	50760	50674	177.6	50454	50895	
Co	1932	1867	1868	1881	1915	1893	29.4	1856	1929	1898	1842	1921	1811	1967	1888	62.2	1811	1965	
Ni	4	19	6	9	9	9	5.8	2	17	5	8	3	4	9	6	2.6	3	9	
Cu	14	20	8	13	4	12	6.1	4	19	15	9	11	9	9	11	2.6	7	14	
Ge	11	5	10	12	4	8	3.6	4	13	5	6	8	23	8	10	7.4	1	19	
Mo	20	15	7	11	11	13	4.9	7	19	15	13	13	39	15	19	11.2	5	33	
Sn	0	4	2	0	0	1	1.8	-1	3	1	3	0	2	2	2	1.1	0	3	
Sb	0	3	2	3	0	2	1.5	0	3	4	2	0	1	1	2	1.5	0	3	

Appendix 8

Pair-wise Comparison Tables (Groups are pipe numbers, i.e. Group 11 is Pipe 1-1)

Group	11	12	13	21	22	23	31	32	33	41	42	43	51	52	53	61	62	63	71	72	73	81	82	83	91	92	93	101	102	103	111	112	113	121	122	123	131
11	x	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
12		x	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
13			x	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
21				x	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
22					x	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
23						x	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
31							x	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
32								x	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
33									x	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
41										x	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
42											x	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	
43												x	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
51													x	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
52														x	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
53															x	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
61																x	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
62																	x	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
63																		x	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
71																			x	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
72																				x	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
73																					x	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
81																						x	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
82																							x	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
83																								x	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
91																									x	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
92																										x	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	
93																											x	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
101																												x	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	
102																													x	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
103																														x	Yes	Yes	Yes	Yes	Yes	Yes	
111																															x	Yes	Yes	Yes	No	Yes	
112																																x	Yes	Yes	Yes	Yes	
113																																	x	Yes	Yes	Yes	
121																																		x	Yes	Yes	
122																																			x	Yes	
123																																				x	
131																																				x	

Phosphorus – 4 samples differentiated

Group	11	12	13	21	22	23	31	32	33	41	42	43	51	52	53	61	62	63	71	72	73	81	82	83	91	92	93	101	102	103	111	112	113	121	122	123	131	
11	x	No	Yes	No	No	No	No	Yes	No	Yes	No	No	Yes	Yes	Yes	No	No	No	Yes	Yes	Yes	Yes	No	Yes	No	No	Yes	Yes	Yes	Yes	No	No	No	No	Yes	No	Yes	
12		x	No	No	Yes	No	No	No	No	No	No	No	No	No	No	No	Yes	Yes	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	
13			x	No	No	No	No	Yes	No	Yes	No	No	Yes	Yes	No	No	No	No	Yes	Yes	Yes	Yes	No	Yes	No	No	Yes	Yes	Yes	Yes	No	No	No	No	Yes	No	Yes	
21				x	No	Yes	Yes	No	Yes	No	Yes	Yes	No	Yes	Yes	Yes	No	No	No	No	No	Yes	Yes	Yes	No	Yes	Yes	No	No	No	No	No	No	Yes	No	Yes	No	
22					x	No	No	No	No	No	No	No	Yes	No	No	No	Yes	Yes	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	
23						x	No	No	No	No	Yes	No	No	No	No	Yes	No	No	No	No	No	No	No	Yes	No	Yes	Yes	No	No	No	No	No	No	No	Yes	No	No	No
31							x	Yes	Yes	No	Yes	Yes	No	Yes	Yes	Yes	No	No	No	No	Yes	Yes	Yes	No	Yes	Yes	No	Yes	No	No	No	No	No	No	Yes	Yes	Yes	Yes
32								x	Yes	No	Yes	Yes	Yes	Yes	Yes	No	No	No	No	Yes	Yes	Yes	Yes	No	Yes	Yes	No	Yes	Yes	Yes	No	No	No	Yes	Yes	Yes	Yes	
33								x	No	Yes	Yes	No	Yes	Yes	Yes	No	No	No	No	Yes	Yes	Yes	No	Yes	Yes	No	Yes	No	No	No	No	No	No	Yes	Yes	Yes	Yes	
41									x	No	No	Yes	No	No	No	No	No	Yes	Yes	No	No	No	Yes	No	No	Yes	Yes	Yes	Yes	No	Yes	Yes	No	Yes	No	No	No	
42										x	Yes	No	Yes	Yes	Yes	No	No	No	No	Yes	Yes	Yes	No	Yes	No	Yes	Yes	No	Yes	No	No	No	No	Yes	Yes	Yes	Yes	
43												x	No	Yes	Yes	Yes	No	No	No	No	Yes	Yes	Yes	No	Yes	Yes	No	Yes	No	No	No	No	No	Yes	Yes	Yes	Yes	
51													x	Yes	No	No	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	No	Yes
52														x	Yes	Yes	No	No	No	No	Yes	Yes	Yes	No	Yes	Yes	No	Yes	No	Yes	No	No	No	Yes	Yes	Yes	Yes	
53															x	No	No	No	No	No	Yes	Yes	Yes	No	Yes	Yes	No	Yes	No	No	No	No	No	Yes	Yes	Yes	Yes	
61																x	No	No	No	No	Yes	No	Yes	No	Yes	Yes	No	No	No	No	No	No	No	No	Yes	No	Yes	No
62																	x	Yes	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	
63																		x	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	
71																				x	Yes	No	No	No	Yes	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	No	No
72																					x	Yes	Yes	No	Yes	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	No	Yes
73																						x	Yes	Yes	No	Yes	Yes	No	Yes	Yes	Yes	No	No	No	Yes	Yes	Yes	Yes
81																							x	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	No	No	No	Yes	Yes	Yes	Yes
82																								x	No	Yes	Yes	No	No	No	No	No	No	No	Yes	Yes	Yes	Yes
83																									x	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	No	No
91																										x	Yes	No	No	No	No	No	No	No	Yes	Yes	Yes	Yes
92																											x	No	Yes	No	No	No	No	No	Yes	Yes	Yes	Yes
93																												x	Yes	Yes	Yes	Yes	Yes	Yes	No	No	No	No
101																													x	Yes	Yes	No	No	Yes	Yes	No	Yes	
102																																						

Chromium – 382 samples differentiated, 57%

Group	11	12	13	21	22	23	31	32	33	41	42	43	51	52	53	61	62	63	71	72	73	81	82	83	91	92	93	101	102	103	111	112	113	121	122	123	131		
11	x	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	No	Yes	Yes	Yes	Yes	No	Yes	No	No	No	No	Yes	Yes	Yes	Yes	No	No	No	No	Yes	Yes	Yes	Yes	
12		x	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	No	Yes	Yes	Yes	Yes	No	Yes	No	No	No	Yes	Yes	Yes	Yes	Yes	No	No	No	No	Yes	Yes	Yes	Yes	
13			x	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	No	No	No	No	Yes	Yes	Yes	Yes	No	Yes	No	No	No	No	Yes	Yes	Yes	Yes	Yes	No	No	No	No	No	No	Yes	
21				x	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	No	Yes	Yes	Yes	Yes	No	Yes	No	No	No	No	Yes	Yes	Yes	Yes	Yes	No	No	No	No	Yes	Yes	Yes	
22					x	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	No	Yes	Yes	Yes	Yes	No	Yes	No	No	No	No	Yes	Yes	Yes	Yes	Yes	No	No	No	No	Yes	No	Yes	
23						x	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	No	Yes	Yes	Yes	Yes	No	Yes	No	No	No	Yes	Yes	Yes	No	No	No	No	No	No	No	Yes	Yes	Yes	Yes
31							x	Yes	Yes	Yes	Yes	Yes	Yes	No	No	No	Yes	Yes	Yes	Yes	No	Yes	No	No	No	Yes	Yes	Yes	Yes	Yes	No	No	No	Yes	Yes	Yes	Yes	Yes	
32								x	Yes	Yes	Yes	Yes	Yes	No	Yes	No	Yes	Yes	Yes	Yes	No	Yes	No	No	No	Yes	Yes	Yes	Yes	Yes	No	No	No	Yes	Yes	Yes	Yes	Yes	
33									x	Yes	Yes	Yes	Yes	No	No	No	Yes	Yes	Yes	Yes	No	Yes	No	No	No	Yes	Yes	Yes	No	Yes	No	No	No	Yes	Yes	Yes	Yes	Yes	
41										x	Yes	Yes	Yes	No	No	No	Yes	Yes	Yes	Yes	No	Yes	No	No	No	No	Yes	Yes	Yes	Yes	No	No	No	No	Yes	No	Yes	Yes	
42											x	Yes	Yes	No	Yes	No	Yes	Yes	Yes	Yes	No	Yes	No	No	No	Yes	Yes	Yes	Yes	Yes	No	No	No	Yes	Yes	Yes	Yes	Yes	
43												x	Yes	No	No	No	Yes	Yes	Yes	Yes	No	Yes	No	No	No	No	Yes	Yes	Yes	Yes	No	No	No	No	Yes	No	Yes	Yes	
51													x	No	No	No	Yes	Yes	Yes	Yes	No	Yes	No	No	No	Yes	Yes	Yes	No	No	No	No	No	Yes	Yes	Yes	Yes	Yes	
52														x	No	Yes	No	No	No	No	Yes	No	Yes	Yes	Yes	Yes	No	Yes	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes	No	
53															x	Yes	No	No	Yes	No	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes	No	No	No	No	No	Yes	Yes	Yes	No	
61																x	No	No	Yes	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes	No	No	No	No	No	Yes	Yes	Yes	Yes	No	
62																	x	Yes	Yes	Yes	No	Yes	No	No	No	Yes	Yes	Yes	No	Yes	No	No	No	Yes	Yes	Yes	Yes	Yes	
63																		x	Yes	Yes	No	Yes	No	No	No	No	Yes	Yes	Yes	Yes	No	No	No	Yes	Yes	Yes	Yes	Yes	
71																			x	Yes	No	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	No	Yes	Yes	Yes	Yes	Yes	
72																				x	No	Yes	No	No	No	Yes	Yes	Yes	Yes	Yes	No	No	No	Yes	Yes	Yes	Yes	Yes	
73																					x	No	Yes	No	Yes	Yes	No	Yes	No	No	Yes	Yes	Yes	Yes	Yes	No	No	No	
81																						x	No	No	No	Yes	Yes	Yes	Yes	Yes	No	No	No	Yes	Yes	Yes	Yes	Yes	
82																							x	Yes	Yes	Yes	No	Yes	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes	No	
83																								x	Yes	Yes	Yes	Yes	No	No	No	Yes	No	Yes	Yes	Yes	Yes	No	
91																									x	Yes	Yes	Yes	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes	No	
92																										x	Yes	Yes	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes	No	
93																											x	Yes	Yes	Yes	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes
101																												x	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
102																													x	Yes	No	No	No	No	No	No	No	Yes	
103																														x	No	No	No	No	No	No	No	Yes	
111																															x	Yes	Yes	No	No	No	No	No	
112																																x	Yes	Yes	No	No	No	No	
113																																	x	Yes	No	No	No	No	
121																																		x	Yes	Yes	No	No	
122																																			x	Yes	Yes	Yes	
123																																				x	No	No	
131																																					x	No	

Manganese – 272 samples differentiated, 41%

Group	11	12	13	21	22	23	31	32	33	41	42	43	51	52	53	61	62	63	71	72	73	81	82	83	91	92	93	101	102	103	111	112	113	121	122	123	131	
11	x	No	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	No	No	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
12		x	No	No	Yes	No	No	No	No	No	No	No	Yes	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	
13			x	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
21				x	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	No	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
22					x	No	No	No	No	No	No	No	Yes	No	Yes	No	Yes	Yes	No	No	No	No	Yes	No	No	No	No	No	No	No	No	No	No	No	No	No	No	
23						x	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	No	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
31							x	Yes	Yes	Yes	No	No	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
32								x	Yes	Yes	Yes	Yes	No	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
33									x	Yes	Yes	Yes	No	Yes	No	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
41										x	Yes	No	No	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
42											x	Yes	No	Yes	No	Yes	No	No	Yes	Yes	Yes	Yes	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
43												x	No	Yes	No	Yes	No	No	Yes	No	Yes	Yes	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
51													x	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	
52														x	No	Yes	No	No	Yes	Yes	Yes	Yes	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
53															x	No	Yes	Yes	No	No	No	No	Yes	Yes	No	No	No	No	No	No	No	No	No	No	Yes	No	No	No
61																	x	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
62																		x	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
63																			x	Yes	No	Yes	No	Yes	No	Yes	Yes	No	No	No	Yes	Yes	No	Yes	Yes	Yes	Yes	
71																				x	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
72																					x	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
73																						x	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
81																							x	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
82																								x	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
83																									x	No	Yes	Yes	Yes	No	Yes	Yes	No	Yes	Yes	Yes	Yes	
91																										x	Yes	No	Yes	Yes	Yes	No	No	Yes	Yes	No	Yes	Yes
92																											x	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
93																												x	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
101																													x	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
102																														x	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
103																															x	Yes	Yes	Yes	Yes	Yes	Yes	
111																																x	Yes	Yes	Yes	Yes	Yes	
112																																	x	Yes	Yes	Yes	Yes	
113																																		x	Yes	Yes	Yes	
121																																			x	Yes	Yes	
122																																				x	Yes	
123																																					x	
131																																					x	

Nickel – 173 samples differentiated, 26%

Group	11	12	13	21	22	23	31	32	33	41	42	43	51	52	53	61	62	63	71	72	73	81	82	83	91	92	93	101	102	103	111	112	113	121	122	123	131	
11	x	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	
12		x	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
13			x	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
21				x	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
22					x	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
23						x	Yes	Yes	Yes	Yes	Yes	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes	No	No	No	No	Yes	Yes	Yes	Yes	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
31							x	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
32								x	Yes	Yes	Yes	Yes	No	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
33									x	Yes	No	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
41										x	Yes	Yes	No	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
42											x	Yes	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes	No	No	No	No	Yes	Yes	Yes	Yes	No	No	Yes	Yes	Yes	Yes	Yes	Yes	No
43												x	No	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	No	No	No	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
51													x	No	Yes	No	No	No	Yes	No	Yes	Yes	Yes	Yes	No	No	No	Yes	Yes	Yes	No	No	No	Yes	No	No	Yes	
52														x	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	
53															x	No	Yes	No	Yes	No	Yes	Yes	Yes	Yes	No	No	No	Yes	Yes	Yes	Yes	No	No	Yes	No	Yes	Yes	
61																x	Yes	Yes	Yes	Yes	Yes	Yes	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
62																	x	Yes	Yes	Yes	Yes	Yes	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
63																		x	Yes	Yes	Yes	Yes	No	No	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
71																				x	Yes	Yes	Yes	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
72																					x	Yes	No	No	No	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
73																						x	Yes	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	
81																							x	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	No	Yes	
82																							x	Yes	No	No	No	No	Yes	No	No	No	No	No	No	No	No	
83																								x	No	No	No	No	No	No	No	No	No	No	No	No	No	
91																									x	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
92																										x	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
93																											x	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
101																													x	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
102																														x	Yes	Yes	Yes	No	Yes	No	Yes	
103																															x	Yes	Yes	No	Yes	Yes	Yes	
111																																x	Yes	Yes	Yes	Yes	Yes	
112																																	x	Yes	Yes	Yes	Yes	
113																																		x	Yes	Yes	Yes	
121																																			x	Yes	Yes	
122																																				x	Yes	
123																																					x	
131																																					x	

Copper – 136 samples differentiated, 20%

Group	11	12	13	21	22	23	31	32	33	41	42	43	51	52	53	61	62	63	71	72	73	81	82	83	91	92	93	101	102	103	111	112	113	121	122	123	131		
11	x	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes		
12		x	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
13			x	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
21				x	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
22					x	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
23						x	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
31							x	Yes	Yes	Yes	Yes	Yes	No	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
32								x	Yes	Yes	Yes	Yes	No	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
33									x	Yes	Yes	Yes	No	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
41										x	Yes	Yes	No	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
42											x	Yes	No	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
43												x	No	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
51													x	No	Yes	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No		
52														x	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
53															x	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No		
61																x	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
62																	x	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
63																		x	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
71																			x	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
72																				x	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
73																					x	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
81																						x	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
82																							x	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
83																								x	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
91																									x	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
92																										x	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
93																											x	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
101																												x	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
102																													x	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
103																														x	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
111																															x	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
112																																x	Yes	Yes	Yes	Yes	Yes	Yes	
113																																							

Titanium – 70 samples differentiated, 11%

Group	11	12	13	21	22	23	31	32	33	41	42	43	51	52	53	61	62	63	71	72	73	81	82	83	91	92	93	101	102	103	111	112	113	121	122	123	131		
11	x	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes		
12		x	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes		
13			x	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes		
21				x	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes		
22					x	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes		
23						x	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes		
31							x	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes		
32								x	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes		
33									x	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes		
41										x	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes		
42											x	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes		
43												x	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes		
51													x	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes		
52														x	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes		
53															x	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes		
61																x	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes		
62																	x	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes		
63																		x	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes		
71																			x	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes		
72																				x	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes		
73																					x	Yes	Yes	No	Yes	Yes	Yes	No	Yes	No	Yes	No	No	Yes	Yes	Yes	Yes		
81																						x	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes		
82																							x	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes		
83																								x	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
91																									x	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
92																										x	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
93																											x	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
101																												x	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
102																													x	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
103																														x	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
111																														x	Yes	No	No	No	No	No	No		
112																															x	Yes	Yes	Yes	Yes	Yes	Yes		
113																																x	Yes	Yes	Yes	Yes	Yes	Yes	
121																																	x	Yes	Yes	Yes	Yes	Yes	
122																																		x	Yes	Yes	Yes	Yes	
123																																				x	Yes	Yes	
131																																						x	Yes

Cobalt – 42 samples differentiated, 6.3%

Group	11	12	13	21	22	23	31	32	33	41	42	43	51	52	53	61	62	63	71	72	73	81	82	83	91	92	93	101	102	103	111	112	113	121	122	123	131	
11	x	No	Yes	No	No	No	No	Yes	No	Yes	No	No	No	No	No	No	No	No	Yes	Yes	No	Yes	No	No	No	No	Yes	Yes	Yes	Yes	No	No	No	No	Yes	No	Yes	
12		x	No	No	Yes	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	
13			x	No	No	No	No	Yes	No	Yes	No	No	No	No	No	No	No	No	Yes	Yes	No	Yes	No	No	No	No	Yes	Yes	Yes	Yes	No	No	No	No	No	No	Yes	
21				x	No	Yes	Yes	No	Yes	No	Yes	Yes	No	No	No	No	No	No	No	No	No	Yes	No	No	No	No	No	No	No	No	No	No	No	No	Yes	No		
22					x	Yes	No	No	No	No	No	No	Yes	No	No	No	Yes	Yes	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	
23						x	No	No	No	No	Yes	No	No	No	No	No	No	No	No	No	No	No	No	No	Yes	No	No	No	No	No	No	No	No	No	Yes	No	No	No
31							x	Yes	Yes	No	No	No	No	No	No	No	No	No	No	No	No	Yes	No	No	No	Yes	No	Yes	No	No	No	No	No	No	Yes	Yes	Yes	Yes
32								x	Yes	No	Yes	Yes	No	No	No	No	No	No	No	Yes	No	Yes	No	No	No	Yes	No	Yes	Yes	Yes	No	No	No	Yes	Yes	Yes	Yes	
33									x	No	Yes	Yes	No	No	No	No	No	No	No	No	No	Yes	No	No	No	Yes	No	Yes	No	No	No	No	No	No	Yes	Yes	Yes	Yes
41										x	No	No	No	No	No	No	No	No	Yes	Yes	No	No	No	No	No	No	Yes	Yes	Yes	Yes	No	No	No	No	No	No	No	No
42											x	Yes	No	No	No	No	No	No	No	No	No	Yes	No	No	No	Yes	No	Yes	No	No	No	No	No	No	Yes	Yes	Yes	Yes
43												x	No	No	No	No	No	No	No	No	No	Yes	No	No	No	No	No	Yes	No	No	No	No	No	No	Yes	No	Yes	
51													x	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	
52														x	No	Yes	No	No	No	No	Yes	No	No	No	Yes	Yes	No	Yes	No	No	No	No	No	No	Yes	Yes	Yes	No
53															x	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	Yes	No	No	No
61																x	No	No	No	No	No	No	Yes	No	Yes	Yes	No	No	No	No	No	No	No	Yes	No	Yes	No	No
62																	x	Yes	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No
63																		x	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	
71																			x	Yes	No	No	No	Yes	No	No	Yes	Yes	Yes	Yes	No	No	No	No	No	No	No	
72																				x	No	Yes	No	No	No	No	Yes	Yes	Yes	Yes	No	No	No	No	No	No	Yes	
73																					x	No	Yes	No	Yes	Yes	No	Yes	No	No	No	No	No	Yes	No	No	No	
81																						x	No	No	No	Yes	Yes	Yes	Yes	Yes	No	No	No	Yes	Yes	Yes	Yes	
82																							x	No	No	Yes	No	No	No	No	No	No	No	No	Yes	Yes	Yes	No
83																								x	No	No	Yes	Yes	No	No	No	Yes	No	No	No	No	No	No
91																									x	Yes	No	No	No	No	No	No	No	No	Yes	No	Yes	No
92																										x	No	Yes	No	No	No	No	No	No	Yes	Yes	Yes	No
93																											x	Yes	Yes	Yes	No	No	No	No	No	No	No	No
101																												x	Yes	Yes	No	No	No	Yes	Yes	No	Yes	
102																													x	Yes	No	No	No	No	No	No	No	
103																														x	No	No	No	No	No	No	Yes	
111																															x	Yes	Yes	No	No	No	No	
112																																x	Yes	No	No	No	No	
113																																	x	No	No	No	No	
121																																		x	Yes	Yes	No	
122																																			x	Yes	Yes	
123																																				x	No	
131																																					x	

Chromium, Manganese, and Nickel – 508 samples differentiated, 76%

Group	11	12	13	21	22	23	31	32	33	41	42	43	51	52	53	61	62	63	71	72	73	81	82	83	91	92	93	101	102	103	111	112	113	121	122	123	131	
11	x	No	Yes	No	No	No	No	Yes	No	Yes	No	No	Yes	No	No	No	No	No	Yes	Yes	No	Yes	No	No	No	No	Yes	Yes	Yes	Yes	No	No	No	No	No	Yes	No	
12		x	No	No	Yes	No	No	No	No	No	No	No	No	No	No	No	Yes	Yes	No	No	No	No	No	No	No	No	No	Yes	Yes	No	No	No	No	No	No	No	No	
13			x	No	No	No	No	Yes	No	Yes	No	No	No	No	No	No	No	No	Yes	Yes	No	Yes	No	No	No	No	Yes	Yes	Yes	Yes	No	No	No	No	No	No	Yes	
21				x	No	Yes	Yes	No	Yes	No	Yes	Yes	No	No	No	No	No	No	No	No	No	Yes	No	No	No	No	No	No	No	No	No	No	No	No	No	Yes	No	
22					x	No	No	No	No	No	No	No	Yes	No	No	No	Yes	Yes	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	
23						x	No	No	No	No	Yes	No	No	No	No	No	No	No	No	No	No	No	No	No	Yes	No	No	No	No	No	No	No	No	Yes	No	No	No	
31							x	Yes	Yes	No	Yes	Yes	No	No	No	No	No	No	No	No	No	Yes	No	No	No	Yes	No	Yes	No	No	No	No	No	Yes	Yes	Yes	Yes	
32								x	Yes	No	Yes	Yes	Yes	No	Yes	No	No	No	No	Yes	No	Yes	No	No	No	Yes	No	Yes	Yes	Yes	No	No	No	Yes	Yes	Yes	Yes	
33									x	No	Yes	Yes	No	No	No	No	No	No	No	No	No	Yes	No	No	No	Yes	No	Yes	No	No	No	No	No	No	Yes	Yes	Yes	
41										x	No	No	Yes	No	No	No	No	No	Yes	Yes	No	No	No	No	No	No	Yes	Yes	Yes	Yes	No	No	No	No	No	No	No	
42											x	Yes	No	No	Yes	No	No	No	No	No	No	Yes	No	No	No	Yes	No	Yes	No	No	No	No	No	Yes	Yes	Yes	Yes	
43												x	No	No	No	No	No	No	No	No	No	Yes	No	No	No	No	No	Yes	No	No	No	No	No	No	Yes	No	Yes	
51													x	No	No	No	Yes	Yes	Yes	Yes	No	Yes	No	No	No	No	Yes	Yes	No	No	No	No	No	No	Yes	No	Yes	
52														x	No	Yes	No	No	No	No	Yes	No	Yes	No	Yes	Yes	No	Yes	No	No	No	No	No	Yes	Yes	Yes	No	
53															x	No	No	No	No	No	No	No	No	No	Yes	Yes	No	Yes	No	No	No	No	No	Yes	Yes	Yes	No	
61																	x	No	No	No	No	No	No	Yes	No	Yes	Yes	No	No	No	No	No	No	Yes	No	Yes	No	
62																		x	Yes	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	
63																				x	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	
71																					x	Yes	No	No	No	Yes	No	Yes	Yes	Yes	Yes	No	No	No	No	No	No	
72																						x	No	Yes	No	No	Yes	Yes	Yes	Yes	No	No	No	No	No	No	Yes	
73																							x	No	Yes	No	Yes	Yes	No	No	No	No	No	No	No	No	No	
81																								x	No	No	Yes	Yes	Yes	Yes	Yes	No	No	No	Yes	Yes	Yes	Yes
82																									x	No	Yes	Yes	No	No	No	No	No	No	Yes	Yes	Yes	No
83																										x	No	Yes	Yes	No	No	No	Yes	No	No	No	No	
91																											x	Yes	No	No	No	No	No	No	Yes	Yes	Yes	No
92																												x	No	Yes	No	No	No	No	Yes	Yes	Yes	No
93																													x	Yes	Yes	Yes	No	No	No	No	No	
101																														x	Yes	Yes	No	No	Yes	Yes	No	Yes
102																															x	Yes	No	No	No	No	No	
103																																x	No	No	No	No	Yes	
111																																	x	Yes	No	No	No	
112																																		x	Yes	No	No	
113																																			x	No	No	
121																																				x	Yes	
122																																					x	
123																																						
131																																						

Chromium, Manganese, Cobalt – 486 samples differentiated, 73%

Group	11	12	13	21	22	23	31	32	33	41	42	43	51	52	53	61	62	63	71	72	73	81	82	83	91	92	93	101	102	103	111	112	113	121	122	123	131
11	x	No	Yes	No	No	No	No	Yes	No	Yes	No	No	Yes	No	No	No	No	No	Yes	Yes	No	Yes	No	No	No	No	Yes	Yes	Yes	Yes	No	No	No	No	Yes	No	Yes
12		x	No	No	Yes	No	No	No	No	No	No	No	No	No	No	No	Yes	Yes	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No
13			x	No	No	No	No	Yes	No	Yes	No	No	No	No	No	No	No	No	Yes	Yes	No	Yes	No	No	No	No	Yes	Yes	Yes	Yes	No	No	No	No	No	No	Yes
21				x	No	Yes	Yes	No	Yes	No	Yes	Yes	No	No	No	No	No	No	No	No	No	Yes	No	No	No	No	No	No	No	No	No	No	No	No	No	Yes	No
22					x	No	No	No	No	No	No	No	No	No	No	No	Yes	Yes	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No
23						x	No	No	No	No	Yes	No	No	No	No	No	No	No	No	No	No	No	No	No	No	Yes	No	No	No	No	No	No	No	Yes	No	No	No
31							x	Yes	Yes	No	Yes	Yes	No	No	No	No	No	No	No	No	No	Yes	No	No	No	Yes	No	Yes	No	No	No	No	No	Yes	Yes	Yes	Yes
32								x	Yes	No	Yes	Yes	No	No	No	No	No	No	No	Yes	No	Yes	No	No	No	Yes	No	Yes	No	Yes	No	No	No	Yes	Yes	Yes	Yes
33									x	No	No	Yes	No	No	No	No	No	No	No	No	No	Yes	No	No	No	Yes	No	Yes	No	No	No	No	No	Yes	Yes	Yes	Yes
41										x	No	No	No	No	No	No	No	No	Yes	Yes	No	No	No	No	No	No	Yes	Yes	No	Yes	No	No	No	No	No	No	No
42											x	Yes	No	No	No	No	No	No	No	No	No	No	No	No	No	Yes	No	Yes	No	No	No	No	No	Yes	Yes	Yes	No
43												x	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	Yes	No	No	No	No	No	No	Yes	No	Yes
51													x	No	No	No	No	No	Yes	No	No	Yes	No	No	No	No	Yes	No	No	No	No	No	No	No	No	No	Yes
52														x	No	Yes	No	No	No	No	Yes	No	No	No	Yes	Yes	No	Yes	No	No	No	No	No	Yes	Yes	Yes	No
53															x	No	No	No	No	No	No	No	No	No	No	No	No	Yes	No	No	No	No	No	Yes	No	Yes	No
61																x	No	No	No	No	No	No	No	No	Yes	Yes	No	No	No	No	No	No	No	Yes	No	Yes	No
62																	x	Yes	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No
63																		x	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No
71																			x	Yes	No	No	No	No	No	No	Yes	Yes	Yes	Yes	No	No	No	No	No	No	No
72																				x	No	No	No	No	No	No	Yes	Yes	No	Yes	No	No	No	No	No	No	Yes
73																					x	No	No	No	Yes	Yes	No	Yes	No	No	No	No	No	Yes	No	No	No
81																						x	No	No	No	Yes	Yes	Yes	Yes	Yes	No	No	No	Yes	No	Yes	Yes
82																							x	No	No	No	No	No	No	No	No	No	No	No	No	No	No
83																								x	No	No	No	No	No	No	No	No	No	No	No	No	No
91																									x	Yes	No	No	No	No	No	No	No	Yes	Yes	Yes	No
92																										x	No	Yes	No	No	No	No	No	Yes	Yes	Yes	No
93																											x	Yes	Yes	Yes	No	No	No	No	No	No	No
101																												x	Yes	Yes	No	No	No	Yes	Yes	No	Yes
102																													x	Yes	No	No	No	No	No	No	No
103																														x	No	No	No	No	No	No	Yes
111																															x	Yes	Yes	No	No	No	No
112																																x	Yes	No	No	No	No
113																																	x	No	No	No	No
121																																		x	Yes	Yes	No
122																																			x	Yes	Yes
123																																				x	No
131																																					x

Chromium, Manganese, Copper – 517 samples differentiated, 78%

Group	11	12	13	21	22	23	31	32	33	41	42	43	51	52	53	61	62	63	71	72	73	81	82	83	91	92	93	101	102	103	111	112	113	121	122	123	131	
11	x	No	Yes	No	No	No	No	Yes	No	Yes	No	No	No	Yes	No	No	No	No	Yes	Yes	Yes	Yes	No	Yes	No	No	Yes	Yes	Yes	Yes	No	No	No	No	Yes	No	Yes	
12		x	No	No	Yes	No	No	No	No	No	No	No	No	No	No	No	No	No	No	Yes	Yes	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	
13			x	No	No	No	No	Yes	No	Yes	No	No	No	Yes	No	No	No	No	Yes	Yes	Yes	Yes	No	Yes	No	No	Yes	Yes	Yes	Yes	No	No	No	No	Yes	No	Yes	
21				x	No	Yes	Yes	No	Yes	No	Yes	Yes	No	Yes	No	Yes	No	No	No	No	Yes	Yes	Yes	No	Yes	Yes	No	No	No	No	No	No	No	Yes	No	Yes	No	
22					x	No	No	No	No	No	No	No	Yes	No	No	No	Yes	Yes	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	
23						x	No	No	No	No	Yes	No	No	No	No	Yes	No	No	No	No	No	No	Yes	No	Yes	Yes	No	No	No	No	No	No	No	Yes	No	No	No	
31							x	Yes	Yes	No	No	No	No	No	No	Yes	No	No	No	No	No	Yes	Yes	No	No	Yes	No	Yes	No	No	No	No	No	Yes	Yes	Yes	Yes	
32								x	Yes	No	Yes	Yes	No	Yes	No	No	No	No	No	Yes	Yes	Yes	Yes	No	No	Yes	No	Yes	Yes	Yes	No	No	No	Yes	Yes	Yes	Yes	
33									x	No	Yes	Yes	No	Yes	No	Yes	No	No	No	No	Yes	Yes	Yes	No	No	Yes	No	Yes	No	No	No	No	No	No	No	Yes	Yes	Yes
41										x	No	No	No	No	No	No	No	No	Yes	Yes	No	No	No	Yes	No	No	Yes	Yes	Yes	Yes	No	Yes	Yes	No	No	No	No	
42											x	Yes	No	Yes	No	Yes	No	No	No	No	Yes	Yes	No	No	Yes	Yes	No	Yes	No	No	No	No	No	Yes	Yes	Yes	Yes	
43												x	No	Yes	No	Yes	No	No	No	No	Yes	Yes	No	No	Yes	Yes	No	Yes	No	No	No	No	No	Yes	Yes	Yes	Yes	
51													x	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	
52														x	No	Yes	No	No	No	No	Yes	Yes	No	No	Yes	Yes	No	Yes	No	Yes	No	No	No	Yes	Yes	Yes	Yes	
53															x	No	No	No	No	No	No	No	Yes	No	No	No	No	No	No	No	No	No	No	Yes	No	No	No	
61																x	No	No	No	No	Yes	No	Yes	No	Yes	Yes	No	No	No	No	No	No	No	Yes	No	Yes	No	
62																	x	Yes	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	
63																		x	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	
71																			x	Yes	No	No	No	Yes	No	No	Yes	Yes	Yes	Yes	No	Yes	Yes	No	No	No	No	
72																				x	Yes	Yes	No	Yes	No	No	Yes	Yes	Yes	Yes	No	Yes	Yes	No	No	No	Yes	
73																					x	Yes	Yes	No	Yes	Yes	No	Yes	No	Yes	No	No	No	No	No	Yes	Yes	
81																						x	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	No	No	No	Yes	Yes	Yes	Yes	
82																							x	No	No	Yes	No	No	No	No	No	No	No	No	Yes	Yes	Yes	Yes
83																								x	No	No	Yes	Yes	Yes	No	No	Yes	No	No	No	No	No	
91																									x	Yes	No	No	No	No	No	No	No	Yes	No	Yes	Yes	
92																										x	No	Yes	No	No	No	No	No	Yes	Yes	Yes	Yes	
93																											x	Yes	Yes	Yes	No	Yes	Yes	No	No	No	No	
101																												x	Yes	Yes	No	No	No	Yes	Yes	No	Yes	
102																													x	Yes	No	No	Yes	No	No	No	No	
103																														x	No	No	Yes	No	Yes	No	Yes	
111																															x	Yes	No	No	No	No	No	
112																																x	Yes	No	No	No	No	
113																																	x	No	No	No	No	
121																																		x	Yes	Yes	Yes	
122																																			x	Yes	Yes	
123																																				x	Yes	
131																																					x	

Chromium, Nickel, Cobalt –444 samples, 67%

Group	11	12	13	21	22	23	31	32	33	41	42	43	51	52	53	61	62	63	71	72	73	81	82	83	91	92	93	101	102	103	111	112	113	121	122	123	131	
11	x	No	Yes	No	No	No	No	Yes	No	Yes	No	No	No	Yes	No	No	No	No	Yes	Yes	Yes	Yes	No	No	No	No	Yes	Yes	Yes	Yes	No	No	No	No	Yes	No	Yes	
12		x	No	No	Yes	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	
13			x	No	No	No	No	Yes	No	Yes	No	No	No	Yes	No	No	No	No	Yes	Yes	Yes	Yes	No	No	No	No	Yes	Yes	Yes	Yes	No	No	No	No	Yes	No	Yes	
21				x	No	Yes	Yes	No	Yes	No	Yes	Yes	No	Yes	No	Yes	No	No	No	No	Yes	Yes	No	No	Yes	Yes	No	No	No	No	No	No	No	Yes	No	Yes	No	
22					x	No	No	No	No	No	No	No	No	No	No	Yes	Yes	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	
23						x	No	No	No	No	Yes	No	No	No	Yes	No	No	No	No	No	No	No	No	Yes	Yes	No	No	No	No	No	No	No	No	Yes	No	No	No	
31							x	Yes	Yes	No	No	No	No	No	Yes	No	No	No	No	Yes	Yes	No	No	No	Yes	No	Yes	No	No	No	No	No	No	Yes	Yes	Yes	Yes	
32								x	Yes	No	Yes	Yes	No	Yes	No	No	No	No	No	Yes	Yes	Yes	No	No	No	Yes	No	Yes	No	Yes	No	No	No	Yes	Yes	Yes	Yes	
33									x	No	No	Yes	No	Yes	No	Yes	No	No	No	No	Yes	Yes	No	No	No	Yes	No	Yes	No	No	No	No	No	Yes	Yes	Yes	Yes	
41										x	No	No	No	No	No	No	No	No	Yes	Yes	No	No	No	No	No	No	Yes	Yes	No	Yes	No	Yes	Yes	No	No	No	No	
42											x	Yes	No	No	No	Yes	No	No	No	No	No	No	No	No	Yes	Yes	No	Yes	No	No	No	No	No	Yes	Yes	Yes	No	
43												x	No	Yes	No	Yes	No	No	No	No	Yes	No	No	No	Yes	Yes	No	Yes	No	No	No	No	No	Yes	Yes	Yes	Yes	
51													x	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	
52														x	No	Yes	No	No	No	No	Yes	Yes	No	No	Yes	Yes	No	Yes	No	Yes	No	No	No	Yes	Yes	Yes	Yes	
53															x	No	No	No	No	No	No	No	Yes	No	No	No	No	No	No	No	No	No	No	Yes	No	No	No	
61																x	No	No	No	No	Yes	No	No	No	Yes	Yes	No	No	No	No	No	No	No	Yes	No	Yes	No	
62																	x	Yes	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	
63																		x	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	
71																				x	Yes	No	No	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	No	No	
72																					x	Yes	No	No	No	No	Yes	Yes	No	Yes	Yes	Yes	Yes	No	No	No	Yes	
73																						x	Yes	No	No	Yes	Yes	No	Yes	Yes	Yes	No	No	No	Yes	Yes	Yes	Yes
81																							x	No	No	Yes	Yes	Yes	Yes	Yes	Yes	No	No	No	Yes	No	Yes	Yes
82																								x	No	No	No	No	No	No	No	No	No	No	No	No	No	No
83																									x	No	No	No	No	No	No	No	No	No	No	No	No	No
91																										x	Yes	No	No	No	No	No	No	Yes	No	Yes	Yes	
92																											x	No	Yes	No	No	No	No	Yes	Yes	Yes	Yes	
93																												x	Yes	Yes	Yes	Yes	Yes	Yes	No	No	No	No
101																													x	Yes	Yes	No	No	No	Yes	Yes	No	Yes
102																														x	Yes	No	No	No	No	No	No	
103																															x	No	No	No	No	Yes	No	Yes
111																																x	Yes	Yes	No	No	No	No
112																																	x	Yes	No	No	No	No
113																																		x	No	No	No	No
121																																			x	Yes	Yes	Yes
122																																				x	Yes	Yes
123																																					x	Yes
131																																						x

Chromium, Nickel, and Copper – 471 samples, 71%

Group	11	12	13	21	22	23	31	32	33	41	42	43	51	52	53	61	62	63	71	72	73	81	82	83	91	92	93	101	102	103	111	112	113	121	122	123	131	
11	x	No	Yes	No	No	No	No	Yes	No	Yes	No	No	No	No	No	No	No	No	Yes	Yes	No	Yes	No	No	No	No	Yes	Yes	Yes	Yes	No	No	No	No	Yes	No	Yes	
12		x	No	No	Yes	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No		
13			x	No	No	No	No	Yes	No	Yes	No	No	No	No	No	No	No	No	Yes	Yes	No	Yes	No	No	No	No	Yes	Yes	Yes	Yes	No	No	No	No	No	No	Yes	
21				x	No	Yes	Yes	No	Yes	No	Yes	Yes	No	No	No	No	No	No	No	No	No	Yes	No	No	No	No	No	No	No	No	No	No	No	No	No	Yes	No	
22					x	No	No	No	No	No	No	No	No	No	No	No	Yes	Yes	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	
23						x	No	No	No	No	Yes	No	No	No	No	No	No	No	No	No	No	No	No	No	No	Yes	No	No	No	No	No	No	No	No	Yes	No	No	No
31							x	Yes	Yes	No	No	No	No	No	No	No	No	No	No	No	No	Yes	No	No	No	Yes	No	Yes	No	No	No	No	No	No	Yes	Yes	Yes	Yes
32								x	Yes	No	Yes	Yes	No	No	No	No	No	No	No	Yes	No	Yes	No	No	No	Yes	No	Yes	No	Yes	No	No	No	Yes	Yes	Yes	Yes	
33									x	No	No	Yes	No	No	No	No	No	No	No	No	No	Yes	No	No	No	Yes	No	Yes	No	No	No	No	No	No	No	Yes	Yes	Yes
41										x	No	No	No	No	No	No	No	No	Yes	Yes	No	No	No	No	No	No	Yes	Yes	No	Yes	No	No	No	No	No	No	No	
42											x	Yes	No	No	No	No	No	No	No	No	No	No	No	No	No	Yes	No	Yes	No	No	No	No	No	Yes	Yes	Yes	No	
43												x	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	Yes	No	No	No	No	No	No	Yes	No	Yes	
51													x	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	
52														x	No	Yes	No	No	No	No	Yes	No	No	No	Yes	Yes	No	Yes	No	No	No	No	No	Yes	Yes	Yes	No	
53															x	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	Yes	No	No	No	
61																x	No	No	No	No	No	No	No	No	Yes	Yes	No	No	No	No	No	No	No	Yes	No	Yes	No	
62																	x	Yes	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	
63																		x	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	
71																			x	Yes	No	No	No	No	No	No	Yes	Yes	Yes	Yes	No	No	No	No	No	No	No	
72																				x	No	No	No	No	No	No	Yes	Yes	No	Yes	No	No	No	No	No	No	Yes	
73																					x	No	No	Yes	Yes	No	Yes	No	No	No	No	No	No	No	No	No	No	
81																						x	No	No	No	Yes	Yes	Yes	Yes	Yes	No	No	No	Yes	No	Yes	Yes	
82																							x	No	No	No	No	No	No	No	No	No	No	No	No	No	No	
83																								x	No	No	No	No	No	No	No	No	No	No	No	No	No	
91																									x	Yes	No	No	No	No	No	No	No	Yes	No	Yes	No	
92																										x	No	Yes	No	No	No	No	No	Yes	Yes	Yes	No	
93																											x	Yes	Yes	Yes	No	No	No	No	No	No	No	
101																												x	Yes	Yes	No	No	No	Yes	Yes	No	Yes	
102																													x	Yes	No	No	No	No	No	No	No	
103																														x	No	No	No	No	No	No	Yes	
111																															x	Yes	No	No	No	No	No	
112																																x	Yes	No	No	No	No	
113																																	x	No	No	No	No	
121																																		x	Yes	Yes	No	
122																																				Yes	Yes	
123																																					x	
131																																					x	

Chromium, Manganese, Copper, Nickel, and Cobalt – 532 samples, 80%