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Analysis of Sampling Data

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ANALYSIS OF SAMPLING DATA

by

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Abstract

A Similar Exposure Group (SEG) can be created through the evaluation of workers performing the same or similar task, hazards they are exposed to, frequency and duration of their exposures, engineering controls available during their operations, personal protective equipment used, and exposure data. For this report, the samples of one facility that has collected nearly 40,000 various types of samples will be evaluated to determine if the creation of a SEG can be supported. The data will be reviewed for consistency with collection methods and laboratory detection limits. A subset of the samples may be selected based on the review.

Data will also be statistically evaluated in order to determine whether the data is sufficient to terminate the sampling. IHDataAnalyst V1.27 will be used to assess the data. This program uses Bayesian Analysis to assist in making determinations. The 95 percent confidence interval will be calculated and evaluated in making decisions. This evaluation will be used to determine if a SEG can be created for any of the workers and determine the need for future sample collection. The data and evaluation presented in this report have been selected and evaluated specifically for the purposes of this project.

Keywords: Similar Exposure Group (SEG), Bayesian, IHDataAnalyst V1.27

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1. Beryllium History

The naturally occurring element, beryllium (Be) was isolated in 1791 by the French chemist, Nicholas Louis Vauquelin. It is a silvery-gray metal with an atomic number of 4 and an atomic mass of 9.0122. Beryllium is the lightest of the metals; has a melting point of 1278°C, the highest of the light metals; is extremely rigid; is non-sparking; non-magnetic; and has a high thermal conductivity. There are ten beryllium isotopes, of which ^{9}Be is the only stable isotope (BSTA, 2015). Figure 1 provides a picture of the isotope in its stable form.

Figure 1. Beryllium

Source: http://periodictable.com/Samples/004.1/s9s.JPG

Beryllium may be present in volcanic dust, soil, rocks oil, coal, and the mineral rock beryl and bertrandite that are mined for their beryllium component. Beryllium (Be) is naturally present in soil, water, and air at low concentrations in certain parts of the United States (ATSDR, PHS- Be, 2002).

Beryllium present in rock, soil, and minerals gets into water and air through erosion. It also enters the air through the burning of coal and fuel oil. Most beryllium is not water-soluble and remains in the soil rather than leaching into the groundwater. In Figure 2 beryl crystals are exposed to the environment, subject to the elements where there is a potential for transport of beryllium containing dust. Environmental Protection Agency (EPA) data found beryllium in five percent of the drinking water samples it tested (ATSDR, PHS- Be, 2002).

Figure 2. Beryl Crystals Ready for Refining

Source: http://elementsunearthed.com/2010/04/14/refining-beryllium-ore/

In air, the majority of particles settle out quickly while other finer particles may remain suspended up to ten days. The Environmental Protection Agency (EPA) has gathered data that shows average background air concentrations of 0.03 nanograms per cubic meter (ng/m^3) of air with an average concentration of 0.2ng/m3 in U.S cities. The higher level in cities is a result of the higher rates of consumption and concentration of oil fuel and coal burning in a centralized area. The smallest particles typically settle out of the air, onto land and waterways within 10 days of becoming airborne. Typical concentrations of beryllium measured in U.S. soil were 3 micrograms per kilogram (μg/kg) of soil (ATSDR, PHS- Be, 2002). Particles settling into the soil have the potential to increase soil concentrations and to become re-entrained in the air through both natural and human actions.

Beryllium alloys are used in a variety of products including computers, automobiles, sporting goods, televisions, calculators, plastic molds, and machinery. Pure forms of beryllium are used in the manufacture of such things as mirrors, x-ray machines, high-tech ceramics, aerospace parts, and nuclear weapons parts and reactors (ATSDR, PHS- Be, 2002).

Some background exposure to beryllium through nature and from consumer goods may exist depending on where you live and consumer goods you use. Individuals living within close proximity to a National Priority List (NPL) site or living near an industry that processes beryllium may be exposed to higher concentrations of beryllium than the rest of the general public. Beryllium is also present in tobacco and may be a source of exposure to cigarette smokers (ATSDR, PHS- Be, 2002).

Occupational exposure to beryllium is the most prevalent source of exposure to higher, elevated concentrations of the chemical. Beryllium is extracted from the earth through mining and the associated processes that separate it from other materials. It may be combined with other metals to form an alloy. Employees that recycle or machine beryllium materials are also at risk of exposure (ATSDR, PHS- Be, 2002). Figure 3 shows molten beryl frit being poured during the process to extract the beryllium. Workers are shown wearing personal protective equipment (PPE) including respiratory protection to reduce the potential for exposure to beryllium fumes.

Figure 3. Pouring Molten Beryl Frit - Be Extraction

Source: http://elementsunearthed.files.wordpress.com/2010/04_molten_pour_3sig.jpg

2. Health Effects of Beryllium Exposure

In the 1930s Europe recognized beryllium as causing lung disease. It wasn't until the 1940s when the United States acknowledged the link (Cooper & Harrison, 2009). Beryllium and beryllium oxide, formed when beryllium is exposed to the oxygen in air, are toxic to humans. Detrimental health effects including Chronic Beryllium Disease (CBD), Beryllium Sensitivity (BeS), lung cancer, and skin disease may result from exposure to beryllium.

2.1. Routes of Exposure

Beryllium may be taken into the body through ingestion of food or water. Plants have the potential to uptake beryllium. It may also be consumed in drinking water, although this is not a prevalent source of exposure in the U.S. Beryllium may also enter the body through an open cut or abrasion in the skin or through inhalation.

When beryllium is ingested, only around one percent will move from the digestive tract into the bloodstream (Cooper & Harrison, 2009). The exposure of cut or abraded skin to beryllium can lead to sores or ulcers. Granulomas may form on the skin when insoluble beryllium becomes trapped under the skin of a beryllium sensitive person and can lead to sensitization (Klaassen, 2013). Dermal exposure to water soluble beryllium can cause papulovesicular dermatitis and conjunctivitis (Cooper & Harrison, 2009).

Acute exposure to beryllium through inhalation is known to cause pneumonitis, coughing, pain in the chest, pneumonia, and dyspnea (Cooper & Harrison, 2009). The entire respiratory tract may become immediately inflamed following exposure and is potentially fatal (Klaassen, 2013).

Chronic Beryllium Disease (CBD), also known as Berylliosis or Chronic Granulomatous Disease, affects the lungs forming lesions. Fibrosis of the lung tissue, interference with alveolar function, and enlargement of the return flow, right side, of the heart may eventually result (Klaassen, 2013, pg 989). Individuals possessing the *HLA-DPB1*^{E69} gene are genetically predisposed to beryllium sensitivity (McCanlies, 2004, Chp.22). Inhaled soluble beryllium that settles in the lungs is slowly released into the bloodstream. In the bloodstream it is often bound in a serum of prealbumin and globulins protein (Klaassen, 2013). In addition to residing in the lungs until it is released, it can also be stored in bone. The "liver, lymph nodes, spleen, heart, muscle, skin, and kidneys" all may receive a dose of soluble beryllium (Klaassen, 2013). The biological half-life of Be is greater than a year because of the amount of time that it will remain in bone and the lungs (Klaassen, 2013).

Beryllium is classified by the International Agency for Research on Cancer (IARC) as a human carcinogen. An increase in the rate in lung cancer cases is associated with exposure; a higher incidence is linked to acute exposure than it is to chronic exposure (Klaassen, 2013).

2.2. Prevalence of Exposure and Disease

The Center for Disease Control (CDC) estimates that in the U.S. worker population 134,000 workers, (26,000 in the either the Department of Energy or the Department of Defense) are currently exposed to beryllium (Henneberger, et al. 2004). A cross-sectional study found that up to ten percent of U.S. workers have beryllium sensitivity. Of this population, ten to 100 percent had developed CBD (NIOSH 2006-2007).

3. Occupational Exposure Limits

Various countries have established occupational exposure limits (OEL) for beryllium including time-weighted average (TWA), short-term exposure limits (STEL), and ceiling (C) limits. International beryllium standards for occupational exposure were available through the World Health Organization (WHO) publication from 1990 and are provided in Table I (WHO

1990). The German Maximale Arbeitsplatz Konzentration (MAK) (maximum workplace concentration) simply denotes “Sah” in the 2008 ACGIH guide to Occupational Exposure Values. “Sah” stands for “danger of sensitization to the airways and the skin,” (ACGIH, 2008).

Table I. Interational Work-Place Exposure Limits

TWA, STEL, C	Exposure Limit (mg/m^3)	Country
TWA	0.001	Czechoslovakia, Hungary
TWA	0.002	Argentina, Austria, Belgium, Bulgaria, Canada, Finland, German Democratic Republic, Italy, Netherlands, Sweden, Switzerland, United Kingdom, USA (OSHA, ACGIH)
TWA	0.0005	USA (NIOSH)
STEL	0.001	Hungary (30 minuite)
STEL	0.002	German Democratic Republic
STEL	0.0025	Argentina
C	0.001	Bulgaria, Poland, Romania, USSR
C	0.002	Czechoslovakia
C	0.005	USA (OSHA)

In the United States, the Occupational Safety and Health Administration (OSHA) established a limit of2 micrograms beryllium per cubic meter of air ($\mu g/m^3$) for respiratory exposure. This is for an 8-hour time-weighted average TWA. OSHA also has a STEL of 5 $\mu g/m^3$ and a ceiling limit of 25 $\mu g/m^3$. These limitations are for the amount of beryllium a worker can be exposed to without adverse health effects. Beryllium is listed under the OSHA 1910.1000 Standard Z Table for Toxic and Hazardous Substances as an air contaminant.

The National Institute of Occupational Safety and Health (NIOSH) has a set limit of 0.5 $\mu g/m^3$ for the recognized carcinogen as TWA and the American Conference of Governmental Industrial Hygienists (ACGIH) has an established TWA limit of 2.0 $\mu g/m^3$.

The Department of Energy has established an action level (AL) of 0.2 $\mu g/m^3$ and an occupational exposure limit of 2.0 $\mu g/m^3$. This is the exposure limit that will be used for this project.

4. Project Specific Information

Beryllium has been machined at Department of Energy facilities since the 1940's.. Beryllium exposure data has been collected for many years at the facility that specializes in machining beryllium. The data has been recorded into the central tracking system since 2000. This report will be used to determine whether a Similar Exposure Group (SEG) can be established for activities performed at this facility and will be analyzed in order to determine the necessity for the continuation of air monitoring at the facility.

5. Similar Exposure Group (SEG)

5.1. Developing a SEG

A Similar Exposure Group (SEG) is a group of workers with common risks and similar exposure that have been grouped together. The similar exposure group may be developed for workers performing the same task or for workers exposed to the same agent or both. In this case, all workers performing tasks in the same area were looked at to determine if there is a potential SEG. Information is provided in the Table I below to show the groups of employees and variables that were taken into consideration.

Table II: Exposure Groups

	Maintenance	Electrician	Fabrication Technician	Machinist	Chemist
Hazard	Beryllium, electrical, various chemicals	Beryllium, electrical	Beryllium	Beryllium, noise	Beryllium, various chemicals
Duration	Variable based on task	Variable based on task	Variable based on task	Variable based on task, weekly up to 8 hours/day	Variable based on task
Frequency	Variable based on task	Variable based on task	Variable based on task	Daily	Variable based on task
Engineering Controls	Variable based on task	Variable based on task	Variable based on task	Variable based on task	Fume Hood
PPE	Standard	Standard	Standard	Standard	Standard

Standard personal protective equipment for work in the facility includes scrubs as an undergarment, with coveralls and booties when wearing footwear designated to use at the facility or two pairs of booties when over footwear not designated to the facility. Full-face air-purifying respirators used with P100 particulate filters are required for certain tasks. Respirators are not considered to be standard PPE as they are not required for general entry into the work area. Respirators are issued by the facility IH for specific tasks with the potential for airborne beryllium exposure.

Upon leaving the machining area, workers first wash their hands then proceed to the downdraft area where they remove their outer coveralls, booties, and shoes if they are designated to the facility. Workers then proceed to the locker room where they are required to shower. Scrubs and undergarments are placed in a designated receptacle for laundering. Engineering controls include general ventilation, localized ventilation, and enclosed machines.

After breaking out the variables associated with the workers, it was determined that there is a lot of variability in the work performed by all of the groups. Work performed by the

Machinists showed the least variability and greatest potential for similar exposures and was further broken down. This group of workers performs several different machining tasks on various beryllium parts. Some activities are routine while others are for specialty orders. Both routine and non-routine machining may involve the use of closed or open machines, wet or dry machining, use of lathes, mills, Computerized Numerical Control (CNC) machines, and wire cutting tools (See Table II).

Engineering controls and PPE for these operations are the same as described above based largely on the type of machine being used to shape the item.

Table III: Machinist Tasks

	Wet Machining	Dry Machining	Open Machines	Closed Machines	Frequency	Duration
Routine Machining of Standard Items	Yes	Yes	Yes	Yes	Daily	*8 hours per day
Non-routine Machining of Specialty Items	Yes	Yes	Yes	Yes	Variable Based on Need	Variable based on part

*Standard machining work shift for the machinists at this facility is 8 hours per day 5 days per week.

5.2. Exposure Assessment and Sampling

Air monitoring using personal sampling pumps has been performed and recorded in the central data tracking system from between 2000 to the present. This data will be looked at to determine if it supports the existence of a Similar Exposure Group and it will also be statistically evaluated to determine the need for future sampling.

5.2.1. Introduction of Sampling Data

Including 4,728 blanks, a total of 39,231 personal air, area air, and surface wipe samples were submitted for analysis during the time period of September 1, 2000 to October 31, 2013.

Personal air sample were collected from the breathing zone of the employee using pre-calibrated personal sampling pumps with sampling train including 0.8-μm cellulose ester membrane filters. Samples were pre calibrated to a range between 1 and 4 liters per minute (LPM) and the pumps were post calibrated after the samples had been collected. Sampling pumps are calibrated using a primary standard calibrator in line with tubing connecting it to the inlet of the sample cassette and tubing connecting the cassette to the sample pump. The Defender® 520 is typically used.

Samples were submitted to ALS, Analytical Laboratory (formerly DataChem) in Salt Lake City, Utah for analysis throughout the eight-year collection period. Samples were analyzed using the National Institute of Safety and Health (NIOSH) Analytical Method Number 7300 for beryllium. The analytical method uses inductively coupled argon plasma, atomic emission spectroscopy (ICP-AES) to determine the amount of beryllium collected onto the sample filter (NIOSH 2013).

5.2.2. Data Set Criteria

The first step in sorting the available data was to separate out personal air samples from surface wipe and area air samples. Second, the job titles of the individuals were sorted to select only those that were Machinists. Activities such as maintenance, chemists, carpenters, electricians, technicians, staff members, machinist fabrication technicians, health and safety support, management, and any other non-machining activities were removed from the data set. Non-routine machining activities were separated out from routine machining activities.

Eight-hour TWA samples were separated from task sampling, samples with incomplete data in the tracking database, and samples with a pre-/post-flow rate difference of the pump exceeding ten percent were not included in the data. In the end, a total of 914 air samples meeting the criteria have been collected. Air sample data is presented in Table VI in Appendix A.

Further narrowing down the available data set, the laboratory limit of quantitation (LOQ) or reporting limit (RL) was reviewed for each sample to account for variations in laboratory's technological capabilities over the course of the sample collection period. Sample results prior to the end of 2011 have a higher analytical reporting limit, up to 0.03 micrograms per sample. The reporting limit recorded in the tracking database dropped to 0.013 micrograms per sample starting with December 6, 2011 data. The laboratory's method to determine limit of detection (LOD) in the earlier samples was not available. Presently, samples with an LOQ/RL of 0.013 µg also have an LOD of 0.0038 µg per sample. Samples prior to the reduction in the reporting limit will not be used for determining whether sampling can be terminated. The reason for this is to establish consistency in the data that will be used to make the determinations.

Samples collected for open and closed, and wet and dry machining processes with only general ventilation were chosen for this evaluation. One hundred ninety-two (192) samples remained in the sample set.

Data was downloaded from the central database housing the information on the collected samples and imported into IHDataAnalyst V1.27.

5.2.3. Software Used to Evaluate Data

The data software that was selected for this project is IHDataAnalyst V1.27 (herein referred to as IHDA). The software is commercially available through Exposure Assessment Solutions (EASi) and can be purchased and downloaded from the Internet. Raw data is provided as an attachment. Names and identifying information of workers have been removed to preserve their privacy.

Once entered into IHDA, each data point was reviewed. Data below the analytical laboratory's LOQ was censored. Censored data is presented in IHDA as one-half of the LOQ or 0.0065 $\mu g/m^3$. These data points are important therefore, they need to be included in the statistical analysis. Since we know the true value of the left-censored data must fall between zero and the LOQ we have selected to use half the LOQ. This is a simple way to account for the data and is a commonly accepted practice that has been evaluated by others (Croghan and Egeghy).

5.3. Statistical Evaluation of the Data

5.3.1. Frequency of Distribution

The frequency of distribution of the exposures is presented in Table III and illustrated by the histogram in Figure 4. One hundred seventy-one (171) of the sample results were below the RL of 0.013 µg, 21 were below 0.1 $\mu g/m^3$ (half of the AL), and no sample results were over. The data is right skewed.

Table IV: Frequency Distribution of Exposures

Average TWA Concentration ($\mu g/m^3$)	Frequency
< RL (0.013 µg)	171
≥ 0.013 – ≤ 0.1	21
> 0.1 - ≤ 0.2	0
≥ 0.2	0
Total	192

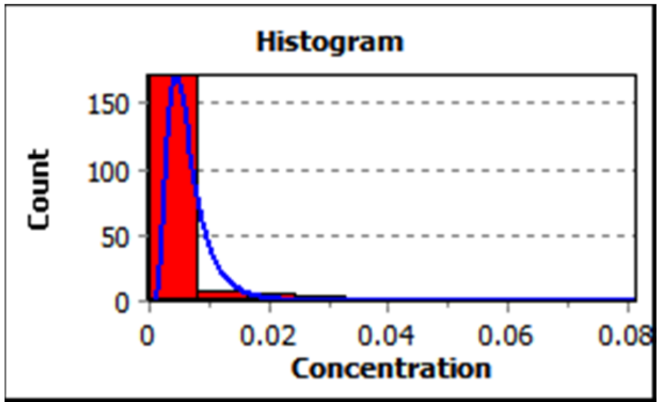

Figure 4. Frequency Distribution Histogram

5.3.2. Statistical Data

One hundred ninety two (192) samples were entered into the software program for analysis. The sample data ranged from 0.0043 to 0.0651-µg/m^3 with a median exposure of 0.0047 µg/m^3. The data set mean is, 0.0121, with a standard deviation (sd) of 0.0721, geometric mean (gm) of 0.0058, and a geometric standard deviation (gsd) of 1.8822.

The confidence interval (CI) was set to 95% with a 95% Lower Confidence Limit (LCL) and 95% Upper Confidence Limits (UCL) for regulatory compliance with OSHA standards. The calculated LCL is 0.0146 with an UCL of 0.0185. At this level, we are confident that 95% of the true values of the samples will fall within the range of the LCL to the UCL, 0.0146 to 0.0185. These concentrations are well below the DOE AL of 0.2 µg/m^3 and the ACGIH and OSHA TWA of 2.0 µg/m^3. The Exceedance Fraction (percent above the OEL) for both is estimated to be less than 0.001%, significantly below the standard 5%. A summary of the statistical data from IHDA is provided in Table IV. Figure 5 provides a Goodness of Fit Chart. This chart could be used to evaluate new data to see how well it fits with the existing data. In determining OSHA compliance, the UCL is ≤ 1, therefore, there is no violation.

Table V. Summary of IHDA Statistics

Parameter	**Result** (µg/m^3)
Data Range	0.0043 to 0.0651
Median	0.0047
Mean	0.0121
SD	0.0721
GM	0.0058
GSD	1.8822
LCL compliance	0.0146
UCL compliance	0.0185

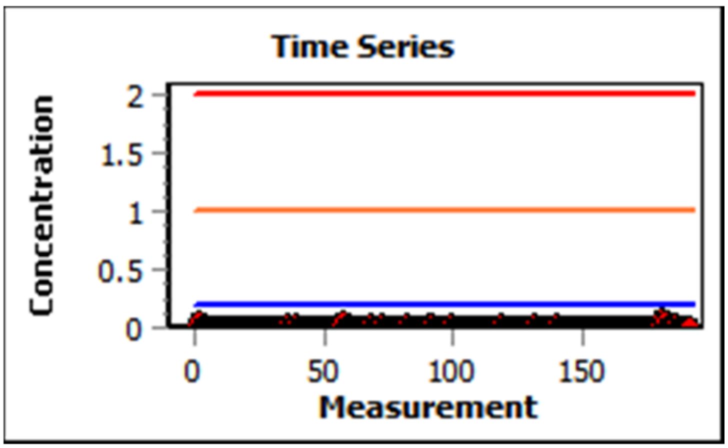

Figure 5. Goodness of Fit Chart

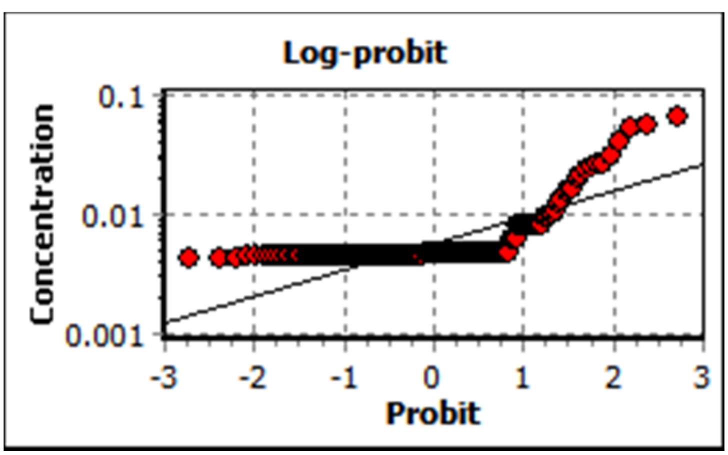

Figure 6. Log Probability Chart

Figure 6 charts the log probability for the existing data. The data does not appear to be log normal as industrial hygiene sampling data tends to be. However, one can see that if the censored data were not included in the chart, it would appear log normal.

5.3.2.1. Bayesian Analysis

The calculated Bayesian Analysis data is provided in Table V below and graphically displayed in the following charts.

Table VI. Bayesian Decision Analysis

Exposure Rating	0-T	1-HC	2-WC	3-C	4-PC
Cutoff (ug.m3)	0.02	0.2	1	2	>2
Cutoff (%OEL)	1	10	50	100	>100
Prior	0.2	0.2	0.2	0.2	0.2
Likelihood	1.000	0.000	0.000	0.000	0.000
Posterior	1.000	0.000	0.000	0.000	0.000
Cumulative Likelihood	1.000	1.000	1.000	1.000	
Cumulative Posterior	1.000	1.000	1.000	1.000	

Table created by IHDA.
Notes:
0 – T = negligible or trivial exposure
1-HC = highly controlled
2-WC = well controlled
3-C = controlled
4-PC = poorly controlled

The probability of the decision statistic falling into each of the exposure rating categories is 0.2 or 1/5th for each category prior to analyzing the data (See Figure 7). An even breakdown of probability was chosen for the Prior Graph before the data was calculated and reviewed to illustrate the there was a 0.2 percent chance of the data falling into any of the rating categories.

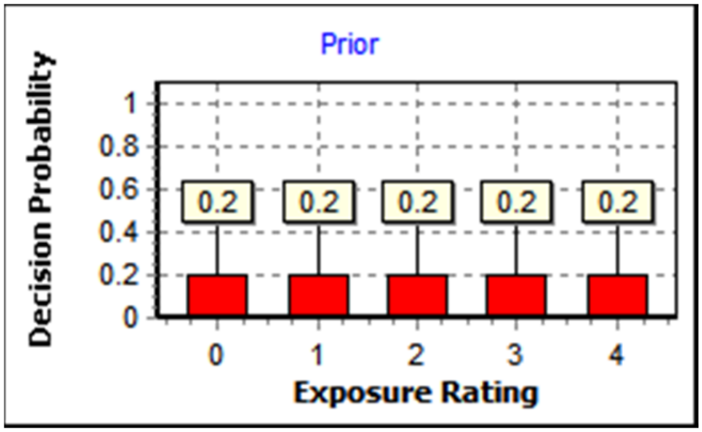

Figure 7. Prior Graph

The likelihood of the sample result falling in the first category is 1 or 100% based on the sampling data (See Figure 8).

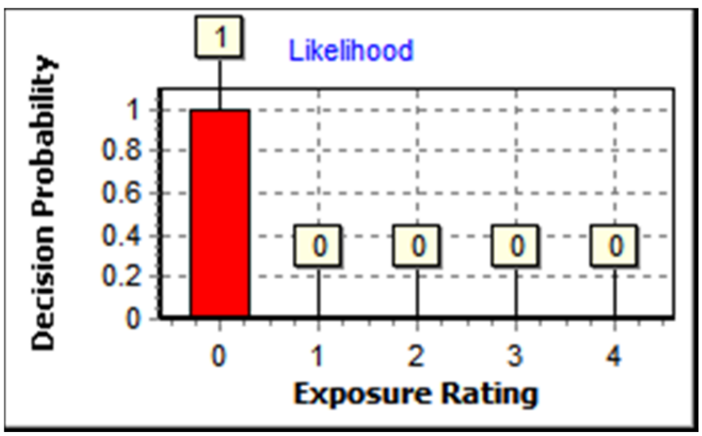

Figure 8. Likelihood Graph

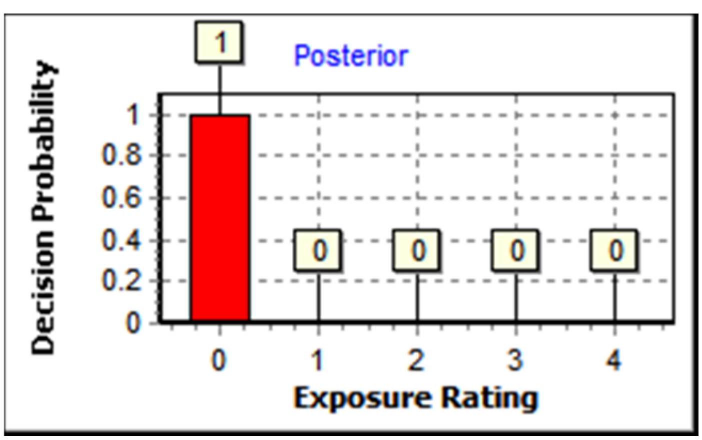

Figure 9. Posterior Graph

Table VII. Exposure Exposure Assessment Controls and Management

Exposure Control Category	Recommended Control
0 (<1% OEL)	No action
1 (<10% OEL)	General Hazcom
2 (10-50% OEL)	+ Chemical specific hazard
3 (50-100% OEL)	+ exposure surveillance, medical surveillance, work practices
4 (>100% OEL)	+ respirator and engineering controls
5 (multiples of OEL, example is based on respirator APFs)	+ immediate engineering controls or process shutdown, validate respirator selection

Based on the Posterior chart, Figure 9, 100% of the samples fall within the 0 Exposure Control Category. All of the samples are less than 1% of the Occupational Exposure Limit concentration. Using the information from the Figure, we refer to Table VI and see that no action is recommended.

5.4. Conclusions

The review of available data yielded a SEG among the Machinists working with beryllium, performing routine activities. The workers in the group are potentially exposed to beryllium during machining on both open and closed machines and with wet and dry machining. General ventilation that has been specially designed to protect workers is in place as an engineering control and workers wear standard PPE while performing work.

Data collected over several years shows similar exposures for workers performing this task and supports the creation of a SEG. Job tasks, hazards, duration, frequency, controls, PPE were evaluated to determine the potential existence of a SEG for workers at the facility. Routine machining activities were identified as a possible SEG. Available sampling data was evaluated to see if it supports the creation of a SEG and to determine the need to continue sampling. The frequency distribution showed that the majority, 171, of the sample results were below the analytical laboratory reporting limit (0.013 µg) and all of the results were equal to or less than

0.1 μg/m^3, half of the reporting limit that has been set at 1/10th of the OEL. One hundred ninety-two personal breathing zone air samples meeting the SEG criteria established for this project have been collected since September2000. The data statistically shows that there is a calculated less than 0.001 percent chance of over exposure to an employee working under these conditions. The GSD for this data set was 1.8822 typical GSD of IH data is 2 to 3. There is slightly less variation in this data set than may be expected. The Goodness of Fit chart could be used to determine if a new data point belongs in this set. In this data set there was the large number of sample results that were below the reporting limit. On the chart, it does not appear that this data fits. However, the data above the RL fits well together and could be illustrated by adding a Goodness of Fit Line to the chart. Statistical analysis of the data supports the idea of making this activity under the given conditions a SEG. The data supports the conclusion that sampling efforts can, with confidence be reduced as prescribed by the DOE Laboratory policy. If changes do occur, the Bayesian Decision analysis can be performed with far fewer samples as it typically is. Any changes in controls or procedures will prompt a reevaluation of the SEG and potential exposures.

In the future, the exposure groups may be further subdivided to identify other SEGs. Due to variations in exposures it is unlikely that there will be a SEG with more than one discipline such as Maintenance and Fabrication. Should another potential SEG be identified, existing data will be identified. If needed, additional sampling will be performed. The data will then be statistically analyzed using IHDA and evaluated to determine compliance and if it supports the creation of a new SEG.

References Cited

Agency for Toxic Substances and Disease Registry. Public Health Statement Beryllium ATDSTR PHS – Beryllium CAS# 7440-41-7. September 2002.

American Conference of Governmental Industrial Hygienists. Guide to Occupational Exposure Values. 2008.

Beryllium Science and Technology Association. Properties of Pure Beryllium. 2015 Retrieved from http://beryllium.eu/about-beryllium-and-beryllium-alloys/properties-of-beryllium/properties-of-pure-beryllium/

Cooper, R. G., and Harrison, A. P. (2009). The uses and adverse effects of beryllium on health. *Indian Journal of Occupational and Environmental Medicine,* 13, 65-76. Retrieved from http://www.ijoem.com/text.asp?2009/13/2/65/55122

Croghan, Carry W., and Egeghy, Peter P. US-EPA, Research Triangle Park, NC and US-EPA, Las Vegas, NM. Methods of Dealing with Values Below the Limit of Detection using SAS. Retrieved from http://analytics.ncsu.edu/sesug/2003/SD08-Croghan.pdf

Henneberger, P.K.; Goe, S.K.; Miller, W.E.; Doney, B.; Groce D.W. (2004). *Journal of Occupational and Environmental Hygiene,* 2004 Oct; 1(10):648-659, Industries in the United States with airborne beryllium exposure and estimates of the number of current workers potentially exposed.

Klaassen, Curtis D. Casarett & Doull's Toxicology: *The Basic Science of Poisons-* 8th ed.. McGraw-Hill Publishers, New York, 2013.

McCanlies, E. C., Andrew M. E., and Weston A. (2004). CDC, Part IV Human Genome Epidemiology: Case Studies: Using human genome epidemiology information to improve health. Chapter 22, Immunogenetic Factors in Chronic Beryllium Disease.

National Research Council Managing Health Effects of Beryllium Exposure by Committee on Beryllium Alloy Exposures, Committee on Toxicology, Published by National Academies Press, Washington, DC, 2008.

National Institute of Occupational Safety and Health. Method 7300, ed. 3. Elements by ICP. March 15, 2003.

National Institute of Occupational Safety and Health. NIOSH Respiratory Disease Research Program, 3.4 Chronic Beryllium Disease. Evidence package for the National Academies' Review 2006-2007.

World Health Organization, IPCS International Programme on Chemical Safety, Health and Safety Guide No. 44, Beryllium. Geneva, Switzerland. 1990.

Appendix A: Table VII. Raw Data

Sample Date	Sample ID	Start Flow (LPM)	Stop Flow (LPM)	Avg Flow (LPM)	Total Time (Minutes)	Air Volume (L)		Concen-tration	TWA Result (ug/m3)
12/6/2011	438	3.213	3.171	3.192	221	700.791	<	0.01855	: < 0.00854
12/7/2011	439	2.982	3.157	3.0695	287	855.834		0.09231	: 0.05519
12/8/2011	440	3.226	2.927	3.0765	321	939.567	<	0.01855	: < 0.00854
12/9/2011	441	3.886	3.192	3.539	302	963.984	<	0.01855	: < 0.00854
1/12/2012	444	3.029	3.008	3.0185	268	806.1	<	0.0161	: <0.0090
1/17/2012	445	3.036	3.058	3.047	238	722.6	<	0.01799	: < 0.00892
1/17/2012	446	2.913	2.911	2.912	59	171.7	<	0.07571	: < 0.00931
1/17/2012	447	3.02	3.267	3.1435	286	863.7	<	0.01505	: < 0.00897
1/18/2012	448	3.061	3.055	3.058	327	999	<	0.01301	: < 0.00886
1/18/2012	449	3.026	3.097	3.0615	325	983.5	<	0.01322	: < 0.00895
1/19/2012	450	3.071	3.08	3.0755	239	734	<	0.01771	: < 0.00882
1/19/2012	451	3.027	3.062	3.0445	423	1280.4	<	0.01015	: < 0.00894
1/20/2012	452	3.077	3.061	3.069	277	847.9	<	0.01533	: < 0.00885
1/30/2012	453	3.074	3.05	3.062	428	1305.4	<	0.0176	: <0.0157
1/30/2012	454	3.015	3.077	3.046	378	1139.7	<	0.0114	: <0.0090
1/31/2012	455	3.627	3.033	3.33	325	985.7	<	0.0233	: <0.0158
2/1/2012	456	3.035	3.569	3.302	236	716.3	<	0.0321	: <0.0158
2/2/2012	457	3.082	3.045	3.0635	439	1336.8	<	0.0172	: <0.0157
2/2/2012	458	3.036	3.009	3.0225	486	1462.4	<	0.0157	: <0.0159
2/3/2012	459	3.045	3.057	3.051	336	1023.1	<	0.0225	: <0.0157
2/13/2012	461	3.04	3.041	3.0405	499	1516.96	<	0.00857	: < 0.00891
2/14/2012	462	3.078	3.063	3.0705	427	1307.9	<	0.00994	: < 0.00884
2/14/2012	463	3.043	3.085	3.064	426	1296.32	<	0.01003	: < 0.0089

2/15/2012	464	3.078	3.05	3.064	369	1125.45	<	0.01155	: < 0.00888
2/15/2012	465	3.05	3.079	3.0645	363	1107.15	<	0.01174	: < 0.00888
2/16/2012	466	3.039	3.058	3.0485	195	592.605	<	0.02194	: < 0.00891
2/16/2012	467	3.012	3.026	3.019	245	737.94	<	0.01762	: < 0.00899
2/17/2012	468	3.064	3.07	3.067	358	1096.91	<	0.01185	: < 0.00884
2/17/2012	469	3.033	3.032	3.0325	353	1070.3	<	0.01215	: < 0.00894
2/20/2012	470	3.087	3.065	3.076	380	1164.7	<	0.0112	: <0.0088
2/20/2012	471	2.948	2.933	2.9405	384	1126.3	<	0.0115	: <0.0092
2/21/2012	472	3.05	3.057	3.0535	399	1217	<	0.0107	: <0.0089
2/21/2012	473	2.926	2.861	2.8935	393	1124.4	<	0.0116	: <0.0095
2/22/2012	474	3.064	3.043	3.0535	292	888.6	<	0.0146	: <0.0089
2/22/2012	475	2.861	2.933	2.897	226	646.6	<	0.0201	: <0.0095
2/28/2012	476	3.078	3.05	3.064	258	786.9		0.0432	: 0.0232
2/28/2012	477	2.955	2.92	2.9375	253	738.8	<	0.0176	: <0.0093
2/29/2012	478	3.049	3.08	3.0645	200	609.8	<	0.0213	: <0.0089
2/29/2012	479	2.92	2.942	2.931	358	1045.4	<	0.0124	: <0.0093
3/1/2012	480	3.083	3.059	3.071	408	1248.07		0.0232	: 0.0198
3/1/2012	481	2.945	2.944	2.9445	434	1277.7	<	0.0102	: <0.0092
3/2/2012	482	3.062	3.059	3.0605	408	1248.07	<	0.0104	: <0.0089
3/2/2012	483	2.943	2.944	2.9435	434	1277.26	<	0.0102	: <0.0092
3/12/2012	484	3.054	3.058	3.056	260	794.04	<	0.0164	: <0.0089
3/12/2012	485	2.921	2.885	2.903	355	1024.18	<	0.0127	: <0.0094
3/13/2012	486	3.039	3.04	3.0395	257	781.023	<	0.0166	: <0.0089
3/13/2012	487	2.921	3.302	3.1115	258	753.618	<	0.0173	: <0.0093
3/14/2012	488	3.036	3.03	3.033	160	484.8	<	0.0268	: <0.0089

3/14/2012	489	2.918	2.91	2.914	155	451.05	<	0.0288	: <0.0093
3/15/2012	490	3.036	3.057	3.0465	193	585.948	<	0.0222	: <0.0089
3/15/2012	491	2.906	2.898	2.902	191	553.518	<	0.0235	: <0.0093
3/16/2012	492	3.045	3.076	3.0605	146	444.57	<	0.0292	: <0.0089
4/11/2012	518	3.025	3.029	3.027	235	710.9	<	0.0183	: <0.0090
4/11/2012	519	2.895	2.851	2.873	125	356.4	<	0.0365	: <0.0095
4/24/2012	520	3.031	3.04	3.0355	156	472.836	<	0.0275	: <0.0089
4/24/2012	521	2.914	2.909	2.9115	156	453.804	<	0.0286	: <0.0093
4/25/2012	522	3.039	3.055	3.047	219	665.541	<	0.0195	: <0.0089
4/25/2012	523	2.912	2.912	2.912	185	538.72		0.1058	: 0.0408
5/1/2012	524	3.038	3.05	3.044	222	674.436	<	0.0193	: <0.0089
5/1/2012	525	2.908	2.923	2.9155	324	942.192	<	0.0138	: <0.0093
5/2/2012	526	3.049	3.033	3.041	191	579.303	<	0.0224	: <0.0089
5/2/2012	527	2.923	3.397	3.16	333	973.359	<	0.0134	: <0.0093
5/3/2012	528	2.918	3.042	2.98	311	907.498	<	0.0143	: <0.0093
5/3/2012	529	2.918	2.843	2.8805	126	358.218	<	0.0363	: <0.0095
5/4/2012	530	3.038	3.043	3.0405	306	929.628	<	0.0104	: <0.0089
5/4/2012	531	2.84	2.906	2.873	293	832.12	<	0.0156	: <0.0095
5/5/2012	532	3.035	3.043	3.039	394	1195.79	<	0.0109	: <0.0089
5/5/2012	533	2.905	2.855	2.88	414	1181.97	<	0.011	: <0.0095
5/6/2012	534	3.019	3.047	3.033	376	1135.14		0.0326	: 0.0255
5/6/2012	535	2.852	2.846	2.849	495	1408.77	<	0.0092	: <0.0095
5/7/2012	536	3.038	3.028	3.033	227	687.356	<	0.0189	: <0.0089
5/7/2012	537	2.85	2.85	2.85	364	1037.4	<	0.0125	: <0.0095
5/8/2012	538	3.038	3.022	3.03	136	410.992		0.1071	: 0.0303
5/9/2012	539	3.024	3.049	3.0365	366	1106.78	<	0.0117	:

									<0.0090
5/9/2012	540	2.9	2.942	2.921	240	696	<	0.0187	: <0.0093
5/10/2012	541	3.051	3.021	3.036	261	788.481	<	0.0165	: <0.0090
5/10/2012	542	2.947	2.911	2.929	74	215.414	<	0.0603	: <0.0093
5/14/2012	543	3.019	3.035	3.027	252	760.788	<	0.0171	: <0.0090
5/14/2012	544	3.387	2.854	3.1205	122	348.188	<	0.0373	: <0.0095
5/15/2012	545	3.032	3.053	3.0425	138	418.416	<	0.0311	: <0.0089
5/15/2012	546	2.854	2.914	2.884	173	493.742	<	0.0263	: <0.0095
5/16/2012	547	3.051	3.044	3.0475	402	1223.69	<	0.0106	: <0.0089
5/16/2012	548	2.916	2.855	2.8855	367	1047.79		0.0334	: 0.0255
5/21/2012	549	3.042	3.04	3.041	152	462.08	<	0.0281	: <0.0089
5/21/2012	550	2.949	2.869	2.909	190	545.11		0.0238	: 0.0094
5/22/2012	551	3.044	3.066	3.055	238	724.472	<	0.0179	: <0.0089
5/22/2012	552	2.87	2.933	2.9015	270	774.9	<	0.0168	: <0.0094
5/23/2012	553	2.928	2.938	2.933	229	670.512	<	0.0194	: <0.0092
5/24/2012	554	3.048	3.026	3.037	307	928.982	<	0.014	: <0.0090
5/24/2012	555	2.932	2.85	2.891	383	1091.55	<	0.0119	: <0.0095
5/29/2012	556	2.914	2.901	2.9075	320	928.32		0.0248	: 0.0165
5/29/2012	557	3.041	3.038	3.0395	198	601.524		0.0399	: 0.0165
5/30/2012	558	2.91	2.899	2.9045	215	623.285	<	0.0209	: <0.0093
5/30/2012	559	3.041	3.054	3.0475	290	881.89	<	0.0147	: <0.0089
5/31/2012	560	2.849	2.937	2.893	207	589.743	<	0.0217	: <0.0094
5/31/2012	561	3.047	3.054	3.0505	187	569.789	<	0.0228	: <0.0089
6/1/2012	562	2.929	2.867	2.898	340	974.78	<	0.0133	: <0.0094
6/1/2012	563	3.046	3.051	3.0485	320	974.72	<	0.0133	: <0.0089
6/4/2012	564	2.924	2.906	2.915	364	1057.78	<	0.0123	: <0.0093

6/4/2012	565	3.04	3.047	3.0435	264	802.56		0.0449	: 0.0247
6/5/2012	566	2.905	2.903	2.904	249	722.847	<	0.018	: <0.0093
6/5/2012	567	3.048	3.055	3.0515	259	789.432	<	0.0165	: <0.0089
6/7/2012	568	2.906	2.827	2.8665	363	1026.2	<	0.0127	: <0.0096
6/7/2012	569	3.066	3.044	3.055	289	879.716	<	0.0148	: <0.0089
6/8/2012	570	3.04	2.873	2.9565	332	953.836	<	0.0136	: <0.0094
6/8/2012	571	3.04	3.036	3.038	309	938.124	<	0.0139	: <0.0089
6/9/2012	572	2.908	2.851	2.8795	308	878.108	<	0.0148	: <0.0095
6/9/2012	573	3.033	3.046	3.0395	294	891.702	<	0.0146	: <0.0089
6/11/2012	574	3.041	3.038	3.0395	207	628.866	<	0.0207	: <0.0089
6/11/2012	575	2.851	2.849	2.85	351	999.999	<	0.013	: <0.0095
6/12/2012	576	3.034	3.048	3.041	359	1089.21	<	0.0119	: <0.0089
6/12/2012	577	2.855	2.904	2.8795	316	902.18	<	0.0144	: <0.0095
6/13/2012	578	3.042	3.041	3.0415	240	729.84	<	0.0178	: <0.0089
6/13/2012	579	2.915	2.865	2.89	376	1077.24	<	0.0121	: <0.0095
6/14/2012	580	3.038	3.063	3.0505	164	498.232	<	0.0261	: <0.0089
6/14/2012	581	2.902	2.854	2.878	288	821.952	<	0.0158	: <0.0095
6/18/2012	582	3.051	3.047	3.049	183	557.601	<	0.02331	: < 0.00889
6/18/2012	583	2.855	2.862	2.8585	153	436.815	<	0.02976	: < 0.00949
6/19/2012	584	3.056	3.043	3.0495	352	1071.14		0.02054	: 0.01506
6/19/2012	585	2.924	2.856	2.89	358	1022.45	<	0.01271	: < 0.00948
6/20/2012	586	3.053	3.059	3.056	291	888.423	<	0.01463	: < 0.00887
6/20/2012	587	2.857	2.906	2.8815	331	945.667	<	0.01375	: < 0.00948
6/21/2012	588	2.904	2.836	2.87	405	1148.58		0.01132	: 0.00955
6/22/2012	589	3.04	3.027	3.0335	260	787.02	<	0.01652	: < 0.00895
6/25/2012	590	3.031	3.043	3.037	264	800.184	<	0.0162	:

									<0.0089
6/25/2012	591	2.905	2.9	2.9025	264	765.6	<	0.017	: <0.0093
6/26/2012	592	3.038	3.012	3.025	95	286.14	<	0.0454	: <0.0090
6/26/2012	593	2.9	2.953	2.9265	105	304.5	<	0.0427	: <0.0093
7/12/2012	598	2.849	2.859	2.854	195	555.555	<	0.0234	: < 0.00951
7/16/2012	600	3.049	3.061	3.055	325	990.925	<	0.0131	: <0.0089
7/16/2012	601	2.91	2.927	2.9185	333	969.03	<	0.0134	: <0.0093
7/17/2012	602	3.052	3.043	3.0475	352	1071.14		0.0177	: 0.0130
7/17/2012	603	2.932	2.906	2.919	237	688.722	<	0.0189	: <0.0093
7/18/2012	604	3.052	3.043	3.0475	352	1071.14	<	0.0121	: <0.0089
7/18/2012	605	2.905	2.906	2.9055	237	688.485	<	0.0189	: <0.0093
7/19/2012	606	2.905	2.872	2.8885	361	1036.79	<	0.0125	: <0.0094
7/24/2012	607	2.89	2.878	2.884	98	282.044	<	0.04609	: < 0.00941
7/24/2012	608	3.062	3.063	3.0625	90	275.58	<	0.04717	: < 0.00884
7/25/2012	609	2.881	2.878	2.8795	286	823.108	<	0.01579	: < 0.00941
7/25/2012	610	3.059	3.062	3.0605	324	991.116	<	0.01312	: < 0.00886
7/25/2012	611	2.959	2.982	2.9705	255	754.545		0.03976	: 0.02112
7/26/2012	612	2.877	2.899	2.888	231	664.587	<	0.01956	: < 0.00941
7/26/2012	613	3.061	3.056	3.0585	208	635.648	<	0.02045	: < 0.00886
7/27/2012	614	3.047	3.058	3.0525	228	694.716	<	0.01871	: < 0.00889
7/30/2012	615	2.879	2.913	2.896	286	823.394	<	0.0158	: <0.0094
7/30/2012	616	3.068	3.052	3.06	320	976.64	<	0.0133	: <0.0089
7/31/2012	617	2.904	2.872	2.888	218	626.096	<	0.02076	: < 0.00943
7/31/2012	618	3.052	3.054	3.053	152	463.904	<	0.028	: <0.0089
8/1/2012	619	3.054	3.051	3.0525	177	540.027	<	0.0241	: <0.0089
8/2/2012	620	2.86	2.912	2.886	404	1155.44	<	0.0113	:

									<0.0095
8/2/2012	621	3.048	3.06	3.054	176	536.448	<	0.0242	: <0.0089
8/3/2012	622	2.906	2.912	2.909	404	1174.02	<	0.0111	: <0.0093
8/3/2012	623	3.055	3.06	3.0575	176	537.68	<	0.0242	: <0.0089
8/4/2012	624	2.906	2.904	2.905	496	1440.38	<	0.009	: <0.0093
8/4/2012	625	3.055	3.024	3.0395	447	1351.73	<	0.0096	: <0.0090
8/5/2012	626	3.039	3.045	3.042	372	1130.51	<	0.0115	: <0.0089
8/5/2012	627	2.898	2.888	2.893	522	1507.54	<	0.0086	: <0.0094
8/7/2012	628	3.039	3.038	3.0385	176	534.688	<	0.02431	: < 0.00891
8/7/2012	629	2.887	2.863	2.875	184	526.792	<	0.02468	: < 0.00946
8/8/2012	630	3.035	3.032	3.0335	193	585.176	<	0.02222	: < 0.00893
8/8/2012	631	2.865	2.869	2.867	212	607.38	<	0.0214	: < 0.00945
8/9/2012	632	3.035	3.033	3.034	121	366.993		0.04087	: 0.0103
8/9/2012	633	2.876	7.873	5.3745	120	345.12	<	0.03767	: < 0.00942
8/13/2012	634	2.873	2.879	2.876	121	347.633		0.04027	: 0.01015
8/15/2012	635	3.033	3.128	3.0805	138	418.554	<	0.03106	: < 0.00893
8/16/2012	636	2.878	2.909	2.8935	58	166.924	<	0.0779	: <0.0094
8/16/2012	637	3.046	3.027	3.0365	226	684.102	<	0.019	: < 0.00895
8/20/2012	638	3.028	3.038	3.033	215	651.02	<	0.01997	: < 0.00894
8/23/2012	639	2.922	2.919	2.9205	324	945.756	<	0.01375	: < 0.00928
8/23/2012	640	3.033	3.056	3.0445	176	533.808	<	0.02435	: < 0.00893
9/10/2012	654	2.183	2.178	2.1805	216	470.448	<	0.02763	: < 0.01243
9/11/2012	655	2.183	2.188	2.1855	292	637.436	<	0.02039	: < 0.0124
9/13/2012	656	2.169	2.169	2.169	308	668.052	<	0.01946	: < 0.01249
11/8/2012	681	2.969	2.951	2.96	280	826.28	<	0.02784	: < 0.01624
11/9/2012	682	2.968	2.976	2.972	305	905.24	<	0.02541	: <

									0.01615
11/14/2012	686	2.987	2.967	2.977	374	1109.66	<	0.02073	: < 0.01615
11/15/2012	688	3.541	3.01	3.2755	258	776.58	<	0.02073	: < 0.01615
11/16/2012	689	2.993	2.972	2.9825	253	751.916	<	0.02073	: < 0.01615
11/17/2012	690	3.22	3.032	3.126	200	606.4	<	0.02073	: < 0.01615
11/18/2012	691	2.929	3.052	2.9905	372	1089.59	<	0.02073	: < 0.01615
1/14/2013	718	3.042	3.042	3.042	68	206.856		0.45926	: 0.06506
1/14/2013	719	2.248	2.282	2.265	126	283.248		0.19418	: 0.05097
1/16/2013	722	2.282	2.205	2.2435	270	595.35	<	0.02184	: < 0.01229
6/10/2013	783	3.024	3.015	3.0195	256	771.84	<	0.01684	: < 0.00898
6/12/2013	786	3.019	3.028	3.0235	261	787.959	<	0.0165	: < 0.00897
6/13/2013	787	3.033	3.01	3.0215	285	857.85	<	0.01515	: < 0.009
7/9/2013	809	3.025	2.978	3.0015	295	878.51		0.02049	: 0.01259
7/10/2013	810	2.999	2.988	2.9935	225	672.3	<	0.01934	: < 0.00907
7/11/2013	811	3.026	2.99	3.008	335	1001.65	<	0.01298	: < 0.00906
7/12/2013	812	3.028	2.996	3.012	169	506.324	<	0.02568	: < 0.00904
8/6/2013	828	2.997	3.018	3.0075	280	839.16		0.01668	: 0.00973
8/10/2013	832	2.932	2.997	2.9645	343	1005.68	<	0.01293	: < 0.00924