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A Comparison of "Total Dust" and Inhalable Personal Sampling for Beryllium Exposure.

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Disclaimer

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A Comparison of “Total Dust” and Inhalable Personal Sampling for Beryllium Exposure

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ABSTRACT

In 2009, the American Conference of Governmental Industrial Hygienists (ACGIH) reduced the Beryllium (Be) 8-hr Time Weighted Average Threshold Limit Value (TLV-TWA) from 2.0 μg/m^3 to 0.05 μg/m^3 with an inhalable "I" designation in accordance with ACGIH's particle size-selective criterion for inhalable mass. Currently, per the Department of Energy (DOE) requirements, the Lawrence Livermore National Laboratory (LLNL) is following the Occupational Health and Safety Administration (OSHA) Permissible Exposure Limit (PEL) of 2.0 μg/m^3 as an 8-hr TWA, which is also the 2005 ACGIH TLV-TWA, and an Action Level (AL) of 0.2 μg/m^3 and sampling is performed using the 37mm (total dust) sampling method. Since DOE is considering adopting the newer 2009 TLV guidelines, the goal of this study was to determine if the current method of sampling using the 37mm (total dust) sampler would produce results that are comparable to what would be measured using the IOM (inhalable) sampler specific to the application of high energy explosive work at LLNL's remote experimental test facility at Site 300. Side-by-side personal sampling using the two samplers was performed over an approximately two-week period during chamber re-entry and cleanup procedures following detonation of an explosive assembly containing Beryllium (Be). The average ratio of personal sampling results for the IOM (inhalable) vs. 37-mm (total dust) sampler was 1.1:1 with a P-value of 0.62, indicating that there was no statistically significant difference in the performance of the two samplers. Therefore, for the type of activity monitored during this study, the 37-mm sampling cassette would be considered a suitable alternative to the IOM sampler for collecting inhalable particulate matter, which is important given the many practical and economic advantages that it presents. However, similar comparison studies would be necessary for this conclusion to be applied to other types of activities, where earlier studies have shown that the IOM sampler tends to collect higher concentrations of Be compared to the 37-mm cassette, which could complicate compliance with what is already an extremely low exposure limit.

INTRODUCTION

Beryllium (Be) is a strong yet light-weight metal with a steel-gray appearance used commonly in the aerospace and defense industry for missiles, satellites, and high-speed aircraft due to its resilient properties such as thermal stability, conductivity, and flexural rigidity (Strupp, 2011a). The low density and atomic mass make it relatively transparent to X-rays, thus making it useful in advanced diagnostics applications, such as high-speed optics and radiography.

Be is challenging to work with due to its toxicity as its dusts present both inhalation and dermal exposure hazards, the former being of highest concern. Be exposures in the workplace have been known to cause Be sensitivity (BeS) and inhalation exposures causing chronic beryllium disease (CBD) (Strupp, 2011a; Strupp, 2011b). There have been numerous epidemiological studies assessing exposure-metrics for airborne Be in determining exposure-response relationships (Virji et al., 2011). Virji et al. (2011) studied alternative exposure metrics for airborne Be and the potential role of particle size, chemical form, and solubility in the development of BeS and CBD.

Since Be is used widely across the Department of Energy (DOE) complex, a final rule (10 CFR 850) was issued by DOE in 1999, establishing a requirement for the development and implementation of a CBD prevention program (CBDPP) to be adhered to by all DOE facilities managed by DOE or its contractors. The Occupational Safety and Health Administration Permissible Exposure Limit (PEL) for Be was established as the operative Occupational Exposure Limit (OEL), which remains at 2.0 $\mu g/m^3$ as an 8-hr Time Weighted Average (TWA) since 10 CFR 850 was issued, along with a DOE established Action Level of 0.2 $\mu g/m^3$as an 8-hr TWA (Podonsky, 2010).

The American Conference of Governmental Industrial Hygienists (ACGIH®) provides guidelines for chemical substances and physical agents presented as Threshold Limit Values (TLV®) (ACGIH, 2009). Currently, the Lawrence Livermore National Laboratory (LLNL) operates under the DOE accepted 2005 ACGIH TLV for Be which was established as 2.0 $\mu g/m^3$ as an 8-hr TWA with no designation for inhalable. LLNL's current practice for measuring airborne concentrations of Be is through the use of the 37-mm closed-face-cassette (CFC) analyzing for "total dust". In 2009, ACGIH adopted a new TLV for Be, reducing it from 2.0 $\mu g/m^3$ to 0.05 $\mu g/m^3$, as an 8-hr TWA (ACGIH, 2009). In addition, in accordance with the ACGIH particle size-selective criterion, Be was given an "I" designation which would require sampling be collected as inhalable particulate matter. The DOE has recently requested input from DOE facilities and its contractors on a proposed adoption of the 2009 Be TLV. This proposed adoption presents a potentially significant economic impact for personal sampling requirements, among other Industrial Hygiene (IH) issues including the re-use and repetitive handling of inhalable samplers with potential surface Be contamination, that may render this change to not be technically feasible for the kind of large-scale research performed at LLNL in addition to the potentially significant economic impacts that it might have on research and development (R&D) experiments.

BACKGROUND AND SIGNIFICANCE

Site 300 is an experimental test facility that covers approximately 7000 acres of land located between Livermore and Tracy county lines (Figures 1 and 2). The range is rather expansive with rolling hills and long winding roads that can take an individual 10-15 minutes to get into the remote parts of the site.

Figure 1. Site 300 is located 17 miles east of LLNL Main Site.

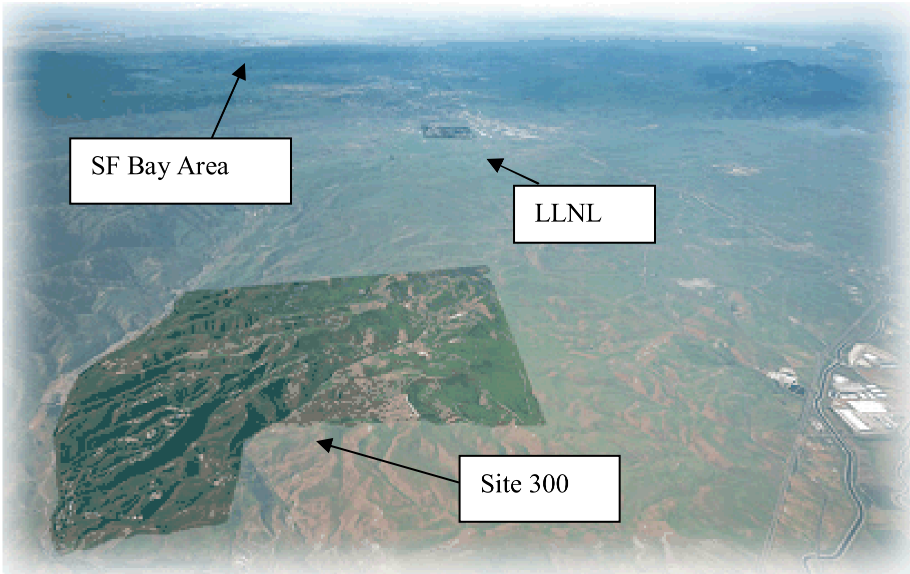
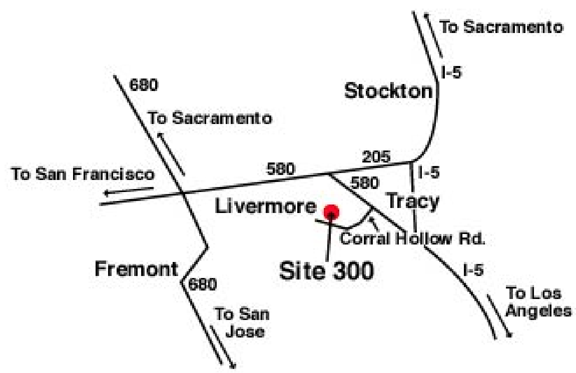


Figure 2. Map of Site 300 and Surrounding Cities

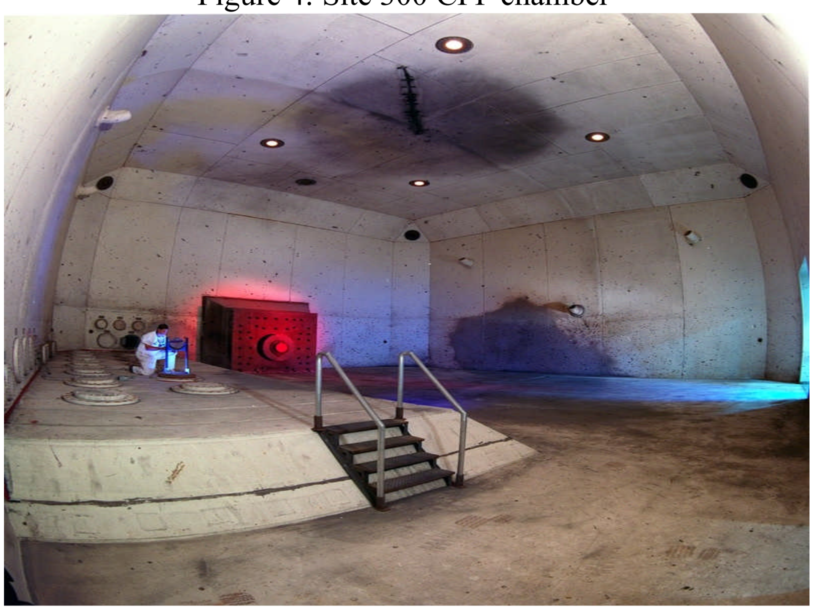


In 1955, Site 300 was established to support explosives testing in nuclear-weapons R&D programs as a remote test site of LLNL. However, after the United States (US) signed a moratorium banning nuclear testing in 1992, it was determined that there was a need for the development of a Stockpile Stewardship Program (SSP) to ensure the reliability and capability of weapons performance. As the US was now tasked to achieve this mission, the DOE would require scientific and engineering institutions to provide support to this program. In 2000, Site 300 built the Contained Firing Facility (CFF) (Figure 3), a one-of-a-kind 28,000-square-foot, concrete-reinforced facility used for large-scale, indoor, hydrodynamic testing. The CFF is capable of withstanding high temperature and pressures, handling up to 60 kg of high explosives, and is designed to fully contain hazardous materials such as Be.

Figure 3. Site 300 Contained Firing Facility (CFF)

There are two types of explosive test areas at Site 300, outdoor and indoor. This research was conducted on the indoor experiments performed inside the CFF chamber (Figure 4). While achieving the DOE/Nuclear National Security Administration (DOE/NNSA) SSP mission is of vital importance to our country, the health, safety, and protection of all workers from workplace disease and illness is the primary concern of an IH and the Occupational Safety and Health Administration (OSHA).

Figure 4: Site 300 CFF chamber



Experimental operations that occur inside the chamber can include additional hazardous materials, Be is the chemical of concern presented in this paper. After an experimental test is performed within CFF, workers enter the chamber to clean and decontaminate the work area to a level that allows the set-up of the next experiment in the chamber without the use of respiratory protection. To address this substantial IH challenge, the hierarchy of controls (engineering, administrative, personal protective equipment (PPE)) have been implemented at CFF to keep OELs as low as possible to ensure worker protection during all operations. However, substitution of Be as a control is not possible as its properties make it a necessary component of the SSP. The ability to perform personal IH sampling inside the chamber, with working wearing multiple layers of PPE, provides challenges on its own. As there is an extensive amount of dust, debris, and material that can become airborne after a shot, the implementation of an extensive control protocol has been necessary to reduce personal exposures as low as feasible to ensure workers are protected. For the purposes of personal IH sampling, this has the positive benefit of sampling results often being below the limit of detection. However, as often times IH research is best performed with detectable sampling results, this can also be seen as a challenge.

In December 2010, there was a proposed rule listed in the Federal Register (2010), under DOE 10 CFR 850, requesting input regarding potential enhancements to the existing CBDPP requirements. As part of this input request, DOE offered an opportunity for LLNL to offer feedback on the following questions: 1) Should DOE continue to use the OSHA permissible exposure limit? 2) Should DOE use the 2010 ACGIH TLV of 0.05 $\mu g/m^3$ as an 8-hr TWA in inhalable particulate matter for its allowable exposure limit? 3) Should an airborne action level (AL) different from the 2010 ACGIH Be TLV be established? If so, what would the level be? (Podonsky, 2010). With these questions presented to LLNL IH experts, among the issues under consideration was whether this proposed rule adopted in the affirmative within the CBDPP could negatively impact the financial and scientific capabilities of Be operations at Site 300 and therefore, a key component of the SSP.

Currently at LLNL, sampling for Be is performed using a 37-mm CFC sampler (Figure 5) and analyzed for both Be and Be oxide as “total Be” utilizing an approved in-house analytical method. If DOE accepts the proposed rule, the Be TLV would serve as the operative OEL and be reduced 40-fold from 2.0 $\mu g/m^3$ to 0.05 $\mu g/m^3$ as an 8-hr TWA. In addition, along with this substantial OEL reduction, the ‘inhalable’ designation for personal sampling would mean a change in personal sampling protocol and could also be seen as an additional challenge. To properly address the question of whether this might be a potential challenge, a side-by-side comparison of the two sampling methods would be necessary. Be experiments that can serve as a worst-case scenario for exposure, resulting in a substantial number of detectable IH personal sampling results, do not occur on a frequent basis at Site 300. Therefore, finding the appropriate opportunity to address this challenge was an additional hurdle to quantifiably determine the effect of a new method of collecting personal exposure data for Be experiments.

The employees performing Be work in the CFF chamber wear respiratory protection with an assigned protection factor (APF) of 1000 performing Be-related tasks. However, under DOE reporting criteria, the APF cannot be taken into account as part of exposure results in the final IH sampling report. Research has shown from side-by-side IH sampling that the use of inhalable sampling cassettes can result in more mass being captured, resulting in higher exposure results for the same task, when compared to 37 mm CFC sampling results (Lee et al., 2011). Therefore, shifting to inhalable sampling methods within CFF could result in an increase in DOE reportable exposure results that would be in excess of what could be a new action level (AL), and perhaps over the new operative OEL, even though extensive controls remain in place for the same tasks and the APF ensures workers are very well protected during the Be-related work operations in the chamber.

Figure 5. “Total dust” 37-mm CFC sampler

Exposure to aerosols and particulates has traditionally been measured in the US using open-face cassettes (OFC) or CFC, for the collection and analysis of the hazards within the “total dust” collected. It is widely understood that the concern of health effects from exposure to particles is not just a function of dose or chemical composition, but includes the size of the particle as well (Tatum et al., 2001). “Total dust” can be seen as not providing optimal information regarding the relative size of the particle sampled, however this traditional method has created a depth of standardized sampling protocol results for researchers to work with in performing research as well as IH risk and exposure assessments.

It has been well documented in a large number of field studies and laboratory studies that the IOM sampler tends to measure higher concentrations than those of the 37-mm CFC when placed side-by-side in a worker’s breathing zone. The IOM sampler/37-mm CFC sampler ratio measured from various wood industries show ratios ranging from around 2 to 4 (Martin and Zalk, 1998; Perrault et al., 1996). Similar comparison studies also indicate that the actual ratios depend on the size of the particles that are generated, with higher ratios measured for activities that generate coarse particles versus activities that generate fine particles (de Vocht et al., 2006; Kenny et al., 1997; Kerr et al., 2002; and Tatum et al., 2001). Various wood dust studies have shown the CFC to under-sample particles in the inhalable range from 0 - 100 µm (Buchan et al., 1986; Lee et al., 2011; Martin and Zalk, 1998; Tatum et al., 2001). Some field comparisons for the IOM and 37 mm samplers (open and closed face) have shown the IOM sampler to collect around 2-3 times more mass than the 37-mm samplers, whereas laboratory comparisons have shown a factor of 1.2 – 1.4 (Kenny et al., 1997).

There are a few types of inhalable samplers on the market: button, GSP conical, multi-orifice (7-Hole), and IOM, but performance has been variable (Adhikari et al., 2003; Lee et al., 2011; Kerr et al., 2002; Sleeth, 2009; Tatum et al., 2001). Therefore, it is important to consider sampler performance requirements to ensure the precision and accuracy for determining personal work exposure levels (Kenny and Bartley, 1995) since different particle size distributions can result in deposition among the different regions of the respiratory tract (Virji et al., 2011).

If DOE accepts the decision to adopt the TLV-TWA as the operative OEL for Be and reduces the standard from 2.0 $\mu g/m^3$ to 0.05 $\mu g/m^3$ (inhalable), it has been postulated that it could negatively impact Be R&D operations at Site 300 both financially and scientifically as it may give the impression that a well-controlled and documented operation would then be perceived as out of compliance. In addition to potentially slowing or stopping R&D in support of the SSP, it could also potentially have adverse impact with our public relations outside LLNL in the absence of discussion behind this resulting from a substantial change in standards and not a change in operations or exposure potential. Therefore, the purpose of this study is to determine if traditional 37-mm "total dust" CFC can be used to sample the inhalable fraction in conformance with ACGIH's particle size-selective criteria. Therefore, the null hypothesis for this research paper is that results of personal sampling with a 37-mm CFC will statistically be considered the same as results from an IOM Inhalable Aerosol Sampler for the same task under the same conditions within the CFF chamber. To address this null hypothesis, an analysis of side-by-side personal sampling data (IOM vs. 37-mm) was conducted during Be decontamination operations in the CFF chamber from May to June 2010.

METHODS AND MATERIALS

Sampler Selection

In May 2010, a side-by-side comparison of personal air sampling was conducted during Be clean-up operations in CFF, in response to the DOE proposal of reducing the operative OEL and accepting the "inhalable" designation instead of "total dust" for determining exposure limits in the field. To better understand the full implications of this change, the 37-mm closed-face-cassette (CFC) "total dust" sampler and the IOM (inhalable) sampler were utilized for this study (Figure 6).

Gilian® 3500 personal air sampling pumps were used for both the IOM and 37-mm CFC samplers in this study. They were calibrated using a primary standard for each pre- and post-sampling session. The IOM sampler was a stainless steel cassette with a plastic body. The flow rate was set at 2.0 L/min. The filter was a 25-mm Mixed Cellulose Ester (MCE) filter. The 37-mm CFC was a three piece cassette. The flow rate was set at 2.5 L/min. The filter was a 37-mm MCE 0.8µ filter.

Figure 6. "Total dust" 37-mm CFC and IOM (Inhalable) samplers

Study Site

Due to the unique operations at CFF, it was determined that the chamber was an excellent choice for performing the comparison study of Be airborne levels. Based on historical data, the airborne Be levels have been measured as high as 24,000 $\mu g/m^3$ in the chamber immediately following an explosive test of a Be-containing high explosive (HE) assembly, prior to any workers entering the chamber and without any controls in place to reduce this level, allowing for an excellent background of dispersible Be and an optimum sampling opportunity for worst-case scenario exposures.

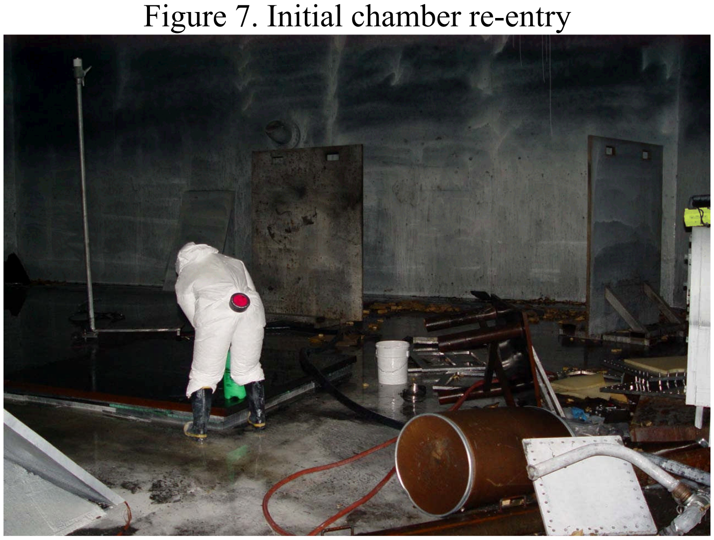
Engineering controls at CFF were designed to minimize exposure to workers prior to the time entry is required for data retrieval and cleanup into the chamber after an experiment. During Be experiments, the chamber is posted as a Regulated Be Work Area (RBWA) which requires the use of a 3-stage decontamination area with shower to ensure that no contamination leaves the work area.

The work area is setup in 3 zones: hot (chamber), warm (buffer area), cold (clean area). Regular controls and housekeeping practices are in place to ensure that we keep personal exposures to a minimum. Through the use of Engineering Controls (wet methods during and after explosive testing, portable High Efficiency Particulate Air (HEPA) vacuums, and in-house HEPA-filtered systems), Administrative Controls (Integrated Worksheets (IWS), Hazards Assessment and Control (HACs), Safety Plans), and PPE (Tyvek coveralls, nitrile gloves, safety shoes, rubber safety boots, respiratory protection), we have been successful in controlling the hazards, minimizing personal exposures, and producing exemplary scientific achievements associated with Be work at CFF.

Day of Experiment

After execution of the Be explosive test, air inside the chamber went through more than 50 air exchanges through a HEPA-filtered exhaust system and the dust generated from the blast was largely captured by barrels of water that were exploded during the experiment. An automatic spray device was placed into the chamber during the initial re-entry (Figure 7) to perform an HE all-clear (safe to re-enter) and film retrieval (often the key R&D experimental result).

Figure 7. Initial chamber re-entry



The clean-up activities (Figure 8) included the following:

- Manual spraying of chamber interior with low-pressure water hoses
- Spraying of encapsulant (Fiberset PM®) on select pieces of equipment
- Consolidation and removal of bulk debris
- Floor squeegee
- Vacuum of chamber ports
- Pushing water into chamber weir
- Spraying of encapsulant on chamber floor, walls, and ceiling

Figure 8. Last steps of CFF chamber cleaning

Sampling

A total of 19 pairs of personal air samples were collected from five different workers, randomly placed on each side of the workers' shoulders and in the workers' breathing zone in accordance with the OSHA Technical Manual (1999). All samples were analyzed by an AIHA-accredited laboratory using a modified ICP method (NIOSH 7300) for collection of elemental Be and Be oxide (Appendix A). The number of sample pairs obtainable was limited by the duration of cleanup, which lasted approximately two weeks, and the number of workers performing cleanup on a given day. A further limiting factor was that only those sample pairs that had detectable Be on both samples were included in the analysis, which left a total of 12 pairs of personal air samples to use for analysis in this research.

Statistical Analysis

Minitab® 16 statistical software package was used to perform the paired t-test of the IOM and 37-mm (8-hr TWA) data. The analysis results are presented in Appendix B. Microsoft Office Excel® 2007 was used to graph and chart data by performing a comparison of personal air sampling data (8-hr TWA) between IOM and 37-mm samplers along with calculating the IOM/37-mm ratios (Table 1) and plotting them on a log-linear graph to display the IOM/37-mm ratio relationship (Figure 9). The purpose of the ratio is to show the under- or over-sampling of the personal sampler such that, "A ratio smaller than one indicates under-sampling of the personal sampler and a ratio larger than one indicates over-sampling of the personal sampler" (de Vocht et al., 2006).

RESULTS

The IOM and 37-mm CFC side-by-side personal air sampling results, along with IOM/37-mm ratios, calculated as an 8-hr TWA, are presented in Table 1. Out of 19 sample pairs that were collected on five separate days of cleanup, 7 sample pairs were excluded from the analysis because at least one result of the pair indicated Be levels below the detection limit, rendering a ratio determination invalid.[1] Therefore, 12 pairs of samples from five different workers (non-detectable results excluded) were compared by performing a paired t-test[2] of the ratios (IOM/37-mm 8-hr TWA) to determine if they are equal to 1.

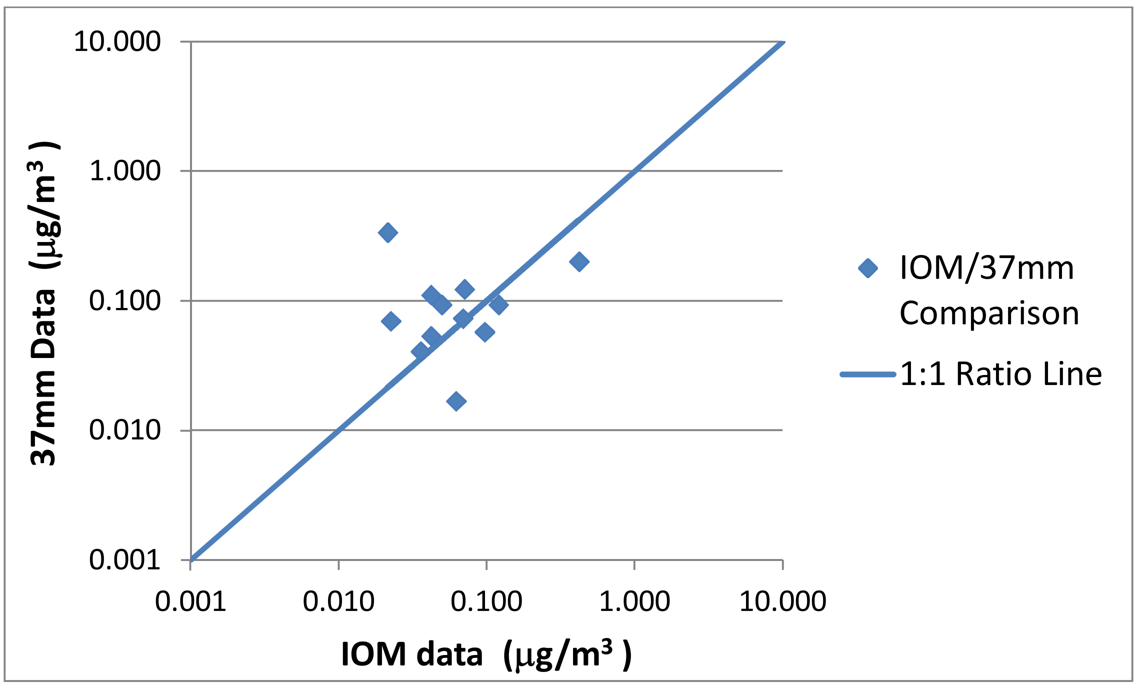
Table 1. Comparison of personal air data (8-hr TWA) from IOM and 37mm sampler

Date	Activity	IOM sampler (mcg/m3)	37mm (mcg/m3)	IOM/37mm Ratio [1]
5/20/2010	Initial Chamber Re-entry (Worker A)	0.071	0.120	0.59
5/20/2010	Initial Chamber Re-entry (Worker B)	0.050	0.093	0.53
5/20/2010	Initial Chamber Re-entry (Worker F)	<0.022	0.019	-
5/25/2010	Chamber Cleanup - Day 1 (Worker B)	< 0.021	< 0.017	-
5/25/2010	Chamber Cleanup - Day 1 (Worker C)	0.062	0.017	3.7
5/25/2010	Chamber Cleanup - Day 1 (Worker D)	0.036	0.041	0.88
5/25/2010	Chamber Cleanup - Day 1 (Worker E)	< 0.018	0.53	-
5/26/2010	Chamber Cleanup - Day 2 (Worker B)	0.097	0.057	1.7
5/26/2010	Chamber Cleanup - Day 2 (Worker C)	<0.021	0.042	-
5/26/2010	Chamber Cleanup - Day 2 (Worker D)	0.022	0.069	0.32
5/26/2010	Chamber Cleanup - Day 2 (Worker E)	< 0.021	< 0.017	-
6/2/2010	Chamber Cleanup - Day 3 (Worker C)	0.069	0.073	0.95
6/2/2010	Chamber Cleanup - Day 3 (Worker D)	0.42	0.20	2.1
6/2/2010	Chamber Cleanup - Day 3 (Worker E)	0.12	0.093	1.3
6/2/2010	Chamber Cleanup - Day 3 (Worker F)	<0.021	<0.017	-
6/3/2010	Chamber Cleanup - Day 4 (Worker B)	<0.021	<0.017	-
6/3/2010	Chamber Cleanup - Day 4 (Worker C)	0.042	0.053	0.79
6/3/2010	Chamber Cleanup - Day 4 (Worker D)	0.021	0.34	0.064
6/3/2010	Chamber Cleanup - Day 4 (Worker E)	0.042	0.11	0.38

[1] Be levels are below the detection limit rendering a ratio determination invalid.
[2] Excel 2007 Descriptive Stats for IOM/37-mm Ratios: P >0.05, P-value = 0.617752, Mean = 1.104, SE = 0.289

The average IOM /37-mm CFC sampler ratio (Table 1), based on 8-hr TWA results, ranged from 0.062 to 3.7, with an average ratio of 1.1:1. Three of the results exceeded the AL of 0.2 μg/m^3. The P-value is 0.62, resulting in no difference between the IOM and 37mm samplers (P >0.05). For all the samples that were collected, workers wore powered air-purifying respirators to provide an APF of 1000; adjusted exposures, therefore, were approximately three orders of magnitude lower than the AL.

Figure 9. Comparison of IOM/37-mm personal air sampler ratios



Using Minitab® 16, descriptive statistics were run on the individual results of IOM and 37-mm (8-hr TWA) data only, no ratios used. The results are presented below in Figures 10 and 11. The IOM and 37-mm data appears to be evenly distributed with the exception of an outlier in both data sets. The assumption of normality cannot be rejected based on the Anderson-Darling Normality Test.

Figure 10. Descriptive statistics for IOM (inhalable) data.

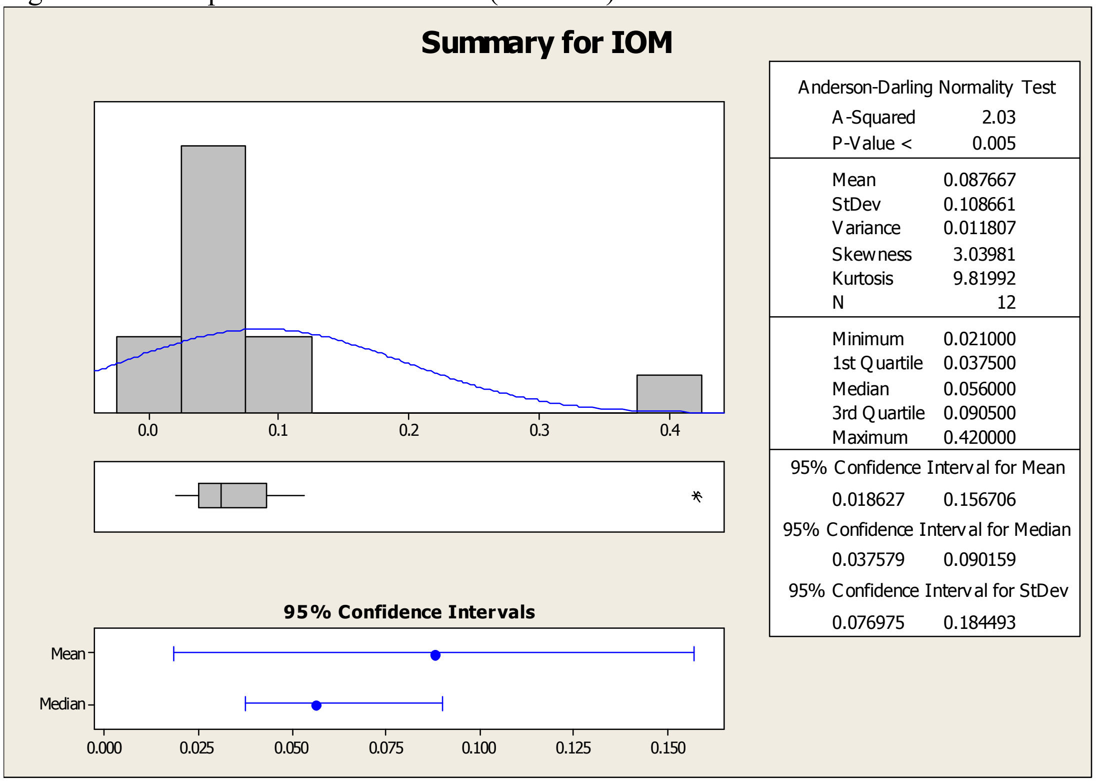
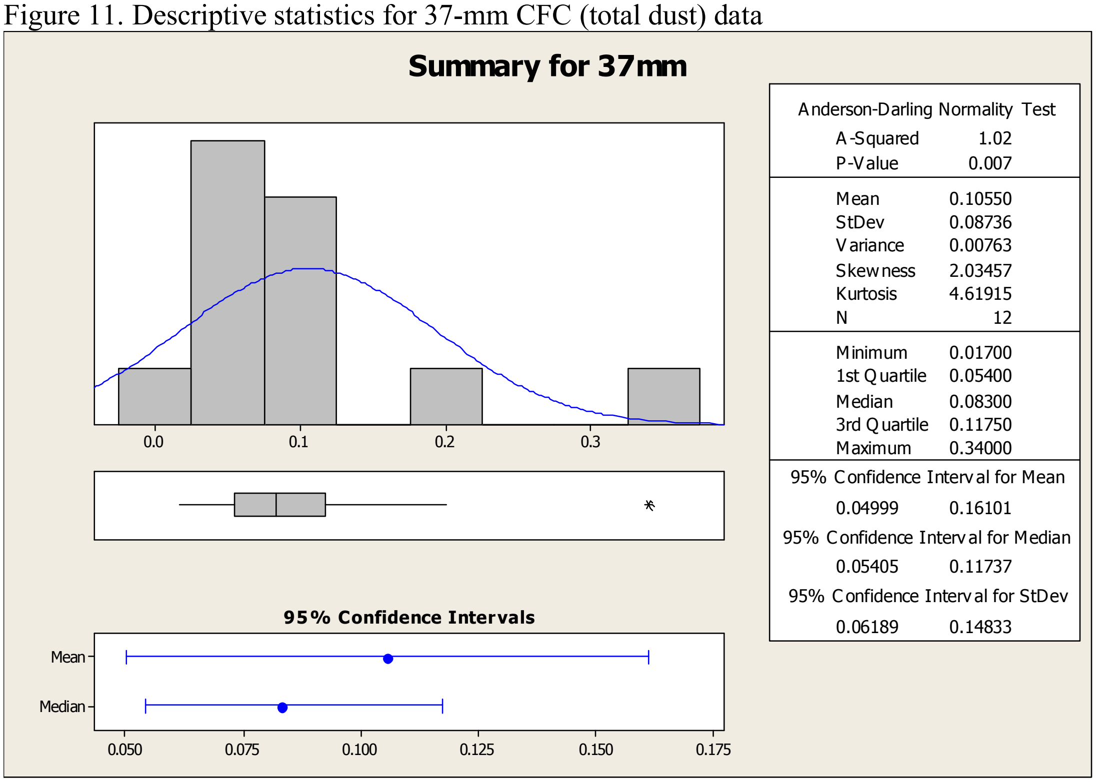


Figure 11. Descriptive statistics for 37-mm CFC (total dust) data



A paired t-test was performed for IOM and 37-mm data (8-hr TWA) (no ratios used), and the results are presented in Figures 12 and 13 and in Appendix B. Figure 12 and 13 show the differences between IOM and 37-mm in relation to the above stated null hypothesis and the 95% confidence internal of the mean. There are a few outliers as well which might be explained by differences in work practices of the 5 individuals that were sampled along with the location of the personal sampler in relation to the airborne material and job tasks (i.e., clean-up versus chamber entry).

Figure 12. Histogram of differences of IOM and 37-mm CFC.

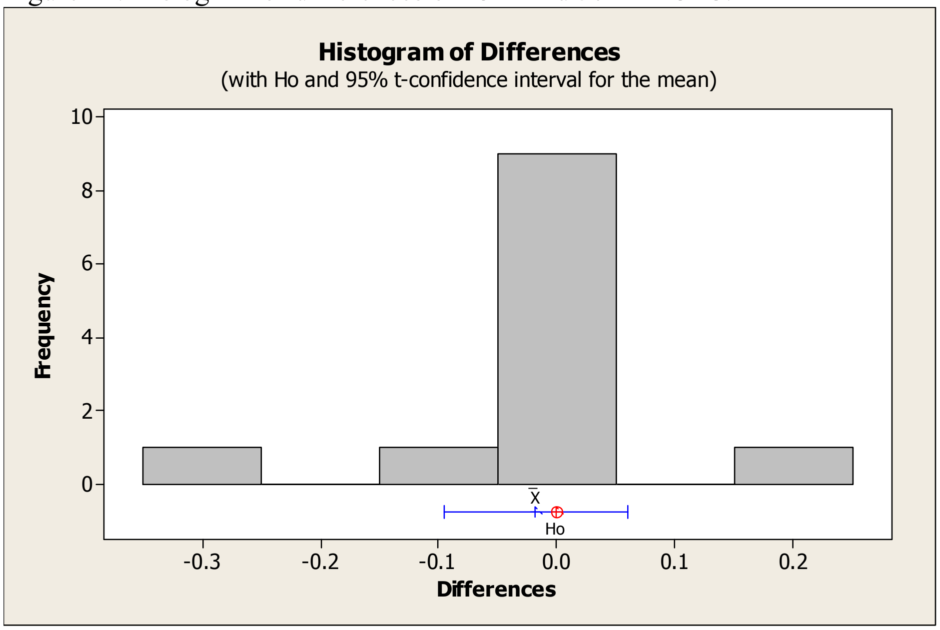
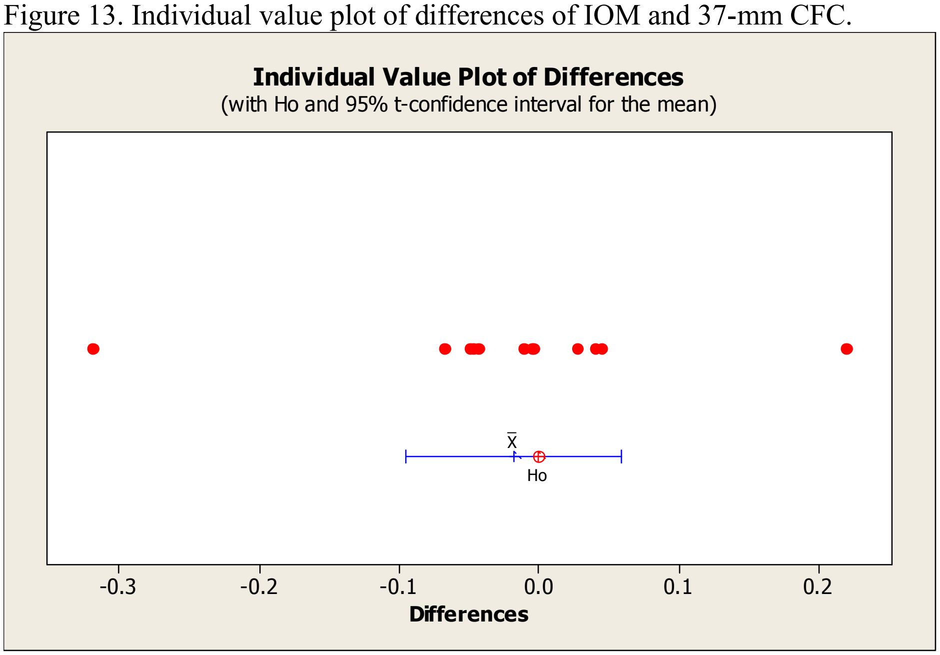


Figure 13. Individual value plot of differences of IOM and 37-mm CFC.



DISCUSSION

Although it has been well documented in field and laboratory studies that the IOM sampler tends to measure higher concentrations than those of the 37-mm CFC when placed side-by-side in a worker's breathing zone, this result was not seen in this research opportunity. For the chamber cleaning operation that was characterized in this study, the average IOM sampler/37-mm CFC sampler ratio was 1.1:1 for personal sampling. While these ratios were closer to unity than one might expect based on the previous comparison studies that were conducted, two important factors should be considered when interpreting this data. First, previous measurements inside the test chamber using an IOM Sampler with a foam insert (for respirable fraction determination) indicated that most of the particles present inside the test chamber were in the respirable range (1-10 μm). This is consistent with the nature of the tests performed inside the chamber, which involves high explosives and an extremely high energy imparted to the components of the experimental assembly, and therefore the generation of very fine particulate.

Secondly, in analyzing the samples for Be, material on both the filters and the internal walls of the cassettes, for both the 37-mm CFC and IOM samplers, were collected and included in the analyses (the inside of the walls were wiped down with a wet swipe tab). A recent study comparing the performance of a 37-mm CFC sampler with ACCU-CAP™ and IOM sampler (Lee et al., 2011) indicated much less discrepancy in performance than previously reported in studies that did not include the ACCU-CAP™ with the 37-mm sampler. The ACCU-CAP™ (SKC Inc., Eighty-Four, PA) is a one-piece filter capsule that fits inside the top and bottom pieces of a two-piece 37-mm sampler that prevents losses of sample that may otherwise be deposited on the interior wall of the cassette. There was also some variability in the ratios calculated for personal air sampling most likely due to spatial variability due to worker's movement and work practices inside the chamber during clean-up. Martin and Zalk (1998) found that variability in the inhalable/CFC ratio was greatest when ambient particulate concentrations were low.

To determine if the measurements from the IOM sampler were significantly different than those from the 37-mm CFC sampler for chamber cleaning operations, a paired t-test was performed for the personal air sample pairs. These resulted in a p-value of 0.62. As the p-value exceeded 0.05, no statistically significant differences were found in the performance of the 37-mm CFC versus the IOM samplers. Thus, as an affirmation of the null hypothesis for the type of activities monitored during this study, personal exposure measurements using a 37-mm CFC would yield similar results to those obtained from an IOM sampler. Therefore, both samplers can be considered as viable options for collecting inhalable particulate matter. It should be recognized, however, that other types of activities may not produce similar results as those obtained in this study. For example, although machining of Be can be considered a high energy activity it is likely to produce coarser particulate and a more variable particulate size range when compared to an explosive testing event, and therefore may result in a greater IOM sampler/37-mm CFC sampler ratio as has been found in other studies. However, further side-by-side studies may be necessary to confirm the ratio obtained as a result of this research and whether the need for a correction factor may need to be applied if using 37-mm CFC sampler results to collect inhalable particulate matter should it be considered a viable and necessary path forward.

The ability to utilize a 37-mm CFC as an alternative to the IOM sampler for determining compliance with an inhalable standard presents several practical benefits. Disposing the inexpensive 37-mm CFCs (< $1 each) after use avoids costs associated with decontaminating the more expensive IOM (or similar non-disposable) sampler, with training personnel in the hazards of the material they would be handling, with required PPE during decontamination, with potential cross-contamination of equipment, and with verifying that the contamination has in fact been effectively removed. It should also be noted that the 37-mm CFC has the additional advantage of not being subject to the “basket effect” and related false positive results associated with the larger orifice of the IOM sampler and which has been well-documented to result in sample over-collection, especially when large particles (> 100 μm in diameter) are present (Liden and Kenny, 1994; Martin and Zalk, 1998; Vaughan et al., 1990).

If ACGIH’s 2009-10 TLV of 0.05 $\mu g/m^3$ is adopted and the AL is set at 10% of the TLV, the result would be an AL of 0.005 $\mu g/m^3$. That limit would fall below the ICP-AES method 7300 for Beryllium (BE) (Appendix A) and no other analytical method would be available to perform the Be analysis. This would create a huge impact on the current and future Be work at Site 300. Overall, Be Work within the U.S. DOE/NNSA complex continues to be of great importance to National Security and the Stockpile Stewardship Program. Further research should focus on reviewing the rationale and logic behind ACGIH’s decision to lower the Be TLV and designate it as an “inhalable” standard.

CONCLUSION

ACGIH’s 2010 TLV-TWA for Be reflects a 40-fold reduction from DOE’s current operative OEL of the 2.0 $\mu g/m^3$ 8-hr TWA OSHA PEL, per 10 CFR 850. If the 2010 TLV-TWA is adopted by DOE, it will largely impact the ability to work with Be within the DOE complex as it would become very difficult to comply with the lowered limit and its associated inhalable criteria. This study presented the results of side-by-side personal sampling using 37-mm CFC and IOM samplers during clean-up operations of a chamber contaminated with dispersible Be from an indoor explosives experiment. The average ratio of personal sampling results for the IOM (inhalable) vs. 37-mm (total dust) sampler was 1.1:1 with a P-value of 0.62, indicating that there was no statistically significant difference in the performance of the two samplers. These results showed that the performance of the 37-mm CFC, regarded as a “total dust” sampler, did not differ significantly from that of an IOM sampler, regarded as an “inhalable aerosol sampler”.

Therefore, for the type of activity monitored during this study, the 37-mm CFC would be considered a suitable alternative to the IOM sampler for collecting inhalable particulate matter, which is important given the many practical advantages that it presents. However, similar comparison studies would be needed for other types of activities as previous studies have shown that the IOM sampler tends to measure much higher concentrations when compared to the 37-mm CFC. The benefits of additional studies for other Be activities of differing energy might also be considered in the DOE Complex as inhalable sampling further adds to the difficulty in complying with an already substantially lowered exposure limit. In the interim, I recommend that an occasional inhalable sample be included in worst-case scenario Be experiments to ensure that nothing has changed in regard to particle size and that the 37-mm CFC is still an adequate choice for Be sampling.

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APPENDIX A

ICP-AES method 7300 for Beryllium (Be)
http://www.cdc.gov/niosh/docs/2003-154/pdfs/7300.pdf

APPLICABILITY:
The working range of this method (7300) is 0.005 to 2.0 mg/m3 for each element in a 500-L air sample. This is simultaneous elemental analysis, not compound specific. Verify that the types of compounds in the samples are soluble with the ashing procedure selected.

APPENDIX B

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Descriptive Statistics: IOM, 37mm

Variable	Total Count	N	N*	CumN	Percent	CumPct	Mean	SE Mean	TrMean	StDev
IOM	12	12	0	12	100	100	0.0877	0.0314	0.0611	0.1087
37mm	12	12	0	12	100	100	0.1055	0.0252	0.0909	0.0874

Variable	Variance	CoefVar	Sum	Sum of Squares	Minimum	Q1	Median	Q3
IOM	0.0118	123.95	1.0520	0.2221	0.0210	0.0375	0.0560	0.0905
37mm	0.0076	82.81	1.2660	0.2175	0.0170	0.0540	0.0830	0.1175

Variable	Maximum	Range	IQR	Mode	N for Mode	Skewness	Kurtosis	MSSD
IOM	0.4200	0.3990	0.0530	0.042	2	3.04	9.82	0.0132
37mm	0.3400	0.3230	0.0635	0.093	2	2.03	4.62	0.0054

* NOTE * Calculating omitted item statistics requires more than 2 variables.

Correction Matrix
Pearson correlation of IOM and 37mm = 0.248

Item and Total Statistics

Variable	Total Count	Mean	StDev
IOM	12	0.08767	0.10866
37mm	12	0.10550	0.08736
Total	12	0.19317	0.15542

Cronbach's Alpha = 0.3905

Paired T-Test and CI: IOM, 37mm

IOM	37mm
0.071	0.120
0.050	0.093
0.062	0.017
0.036	0.041
0.097	0.057
0.022	0.069
0.12	0.093
0.069	0.073
0.420	0.200
0.042	0.110
0.042	0.053
0.021	0.340

Paired T for IOM - 37mm

	N	Mean	StDev	SE Mean
IOM	12	0.0877	0.1087	0.0314
37mm	12	0.1055	0.0874	0.0252
Difference	12	-0.0178	0.1213	0.0350

95% CI for mean difference: (-0.0949, 0.0593)
T-Test of mean difference = 0 (vs not = 0): T-Value = -0.51 **P-Value = 0.621**