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Lead Exposure at a Covered Outdoor Firing Range

J. Bonanno, M. G. Robson, B. Buckley, M. Modica

Environmental and Occupational Health Sciences Institute, 170 Frelinghuysen Road, Piscataway, NJ 08854, USA

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Lead exposures associated with the discharge of firearms at indoor firing ranges began to be quantified in the early 1970s (NIOSH 1974). Over the next 20 years, numerous exposure assessments were performed at both indoor and outdoor firing ranges (Landrigan, et. al. 1975; Anderson, et. al. 1977; Fischbein, et. al. 1979; Novontny, et. al. 1987; Svensson, et. al. 1992; Chau et. al. 1995, Tripathi et. al. 1991). Many of these assessments demonstrated a positive relationship between exposure to elemental lead at indoor firing ranges and excessive absorption of lead and/or symptomology of lead poisoning. Tripathi, et. al. (1991) demonstrated a positive relationship between exposure of firearms instructors to elemental lead at a covered outdoor firing range, and increased blood lead levels. The purpose of this study is to perform an initial investigation into the lead exposure to target shooters using an outdoor covered pistol range.

MATERIALS AND METHOD

Given the evidence of potential excess absorption of lead amongst marksman and range officers, the present study was undertaken. An investigation was designed to assess the potential lead exposures of target shooters participating in organized pistol competitions at a covered outdoor firing range. Airborne lead and lead dust levels, on both horizontal surfaces and shooters hands, were evaluated. The effects of ammunition caliber, ammunition type, and shooting season on airborne lead levels were also examined. This study was unique in that the facility in question, although classified as an outdoor range, maintains a totally enclosed firing line during the winter months. This condition mimics that of a firing line at an indoor range. Also, measurements of lead deposited on each competitor's shooting hand during competitions allowed for verification of the effect of ammunition type on lead exposure.

The facility in question consisted of an enclosed firing line, an enclosed clubhouse, an enclosed kitchen area, and an outdoor target area. The clubhouse, was connected to the firing line by a common doorway. The kitchen and target areas were free standing structures. The condition of the firing line varied based on shooting season. During the summer season, the front wall of firing line was removed in order to improve ventilation (see Figure 1). The front wall was

Correspondence to: M. G. Robson

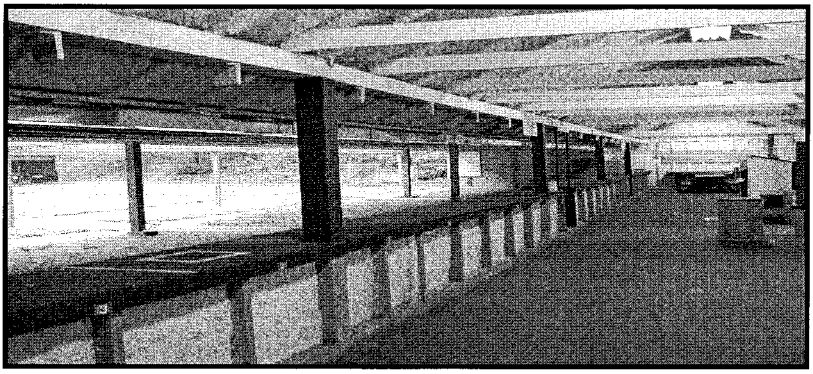

Figure 1. Summer conditions on the firing line.

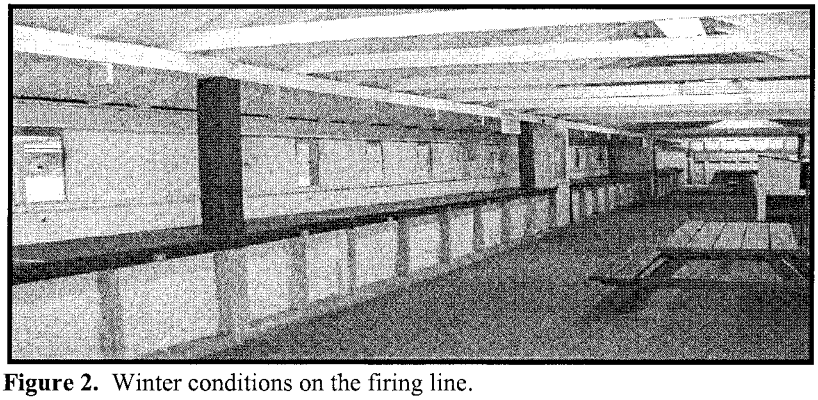

Figure 2. Winter conditions on the firing line.

replaced during the winter season in order to assist in temperature control (see Figure 2).

Personal air samples and hand wipes were collected at each of three competitions held on 8/29/1999, 11/7/1999, and 11/20/1999. Wipes of horizontal surfaces were collected on 8/28/1999. The 8/29 and 11/7 competitions consisted of 22 caliber and center-fire (45 caliber) portions. Each participant in these competitions fired 60 rounds during the 22 caliber portion and 60 rounds during the center-fire portion, for a total of 120 rounds fired per competitor. The overall-firing rate was approximately 30 rounds per 15 minute period, with the total firing time being approximately 1 hour. The 11/20 competition consisted only of a center-fire portion, with each competitor firing 60 rounds of specially designed low-lead 45 caliber ammunition. The firing pattern during the 11/20 competition was identical to the 8/29 and 11/7 competitions and the overall firing time was approximately 30 minutes. Active exhaust ventilation was supplied during the 11/7 competition only. There were nine to sixteen subjects at each competition, nine or ten participated in the sampling. All of the competitors were males. See Tables 1 and 2 for a summary of the sampling conditions during these three competitions.

Table 1. Summary of sampling conditions.

Shoot Date	Status of Front Wall	Status of Active Ventilation	Temperature	Relative Humidity	Type of 45 Caliber Ammunition
8/29/99	Off	Not Present	72°F	85%	Uncontrolled
11/7/99	On	Present – Running	61°F	44%	Uncontrolled
11/20/99	On	Present – Off	60°F	40%	WinClean™

Table 2. Summary of sampling population.

Shoot Date	Number of Shooters	Number of Shooters Sampled	Total Number of Participants Sampled
8/29/99	9[1]	8	10[2]
11/7/99	14	9	9
11/20/99	6	6	7[3]

[1]One shooter declined to wear a pump.
[2]The match caller and the investigator wore sampling pumps, but did not fire pistols.
[3]The match caller wore a sampling pump, but did not fire a pistol.

Personal air samples were collected using Gilian (Model # HFS513A) and AirChek (Model #224-PCXR7) sampling pumps. Collection media consisted of Zeflon – Analytical Accessories Air Monitoring Cassettes (37 mm, 3 pc, 0.8 μm MCE filters), which were mounted at the competitor's collar and connected to sampling pumps via tygon tubing. Sampling pumps were mounted at the competitor's wasteline and were calibrated to a flow rate of 3 liters per minute, against a primary standard (Gilabrator Primary Flow Calibrator Control Unit and Bubble Generator) the morning of each competition. The collection media was removed and replaced between the 22 caliber and center-fire portion of each competition. Flow rate checks were performed with a KL-43 Rotometer (1-5 liters per minute) immediately before and after each media change. The KL-43 Rotometer was calibrated against a primary standard prior to use. Pumps were recalibrated against the Gilabrator at the conclusion of the center-fire portion of each competition. Monitoring cassettes collected on 8/29, 11/7, and 11/20 were analyzed using Graphite Furnace Atomic Absorption (NIOSH Method 7105), Flame Atomic Absorption (NIOSH Method 7082), and ICPMS (NIOSH Method 7300), respectively. Both field and laboratory blanks were collected and analyzed with results from all three competitions.

Wipes of each competitor's shooting hand were collected immediately before and after the 22 caliber and center-fire competitions. Each participant collected wipes by thoroughly swabbing the front, back, and each finger of their shooting hand. Unscented, alcohol-free baby wipes were used as wipe media. After each wipe was collected, competitors were asked to fold the wipe in half twice.

Wipes were folded in a manner that would protect the sample and placed into plastic bags held open by the investigator. Wipes were digested in groups of eleven with the addition of 1 laboratory blank, for a total of twelve samples per batch.

Samples were transferred from plastic bags to plastic digestion vessels using plastic tweezers. Tweezers were cleaned with deionized water and dried after handling each sample. Twenty milliliters of Trace Metals Nitric Acid was added to each digestion vessel and caps were secured loosely. One laboratory blank was prepared with each group of 11 field samples. Laboratory blanks were prepared in the same fashion as field samples and blanks. The digestion vessels were then placed into the microwave carousel and allowed to sit for a period of at least 24 hours prior to being heated. Samples were heated in a CEM MDS-2000 Microwave for a 50 minute cycle. Extract from the digestions was filtered through Whatman filter paper into 50 ml test tubes. All samples were then diluted to 50 ml using deionized water. Next, 2 ml samples were collected from each 50 ml test tube. These samples were then diluted to 12 ml using deionized water. Each 12 ml sample was then analyzed for lead using a Fissons PQ3 ICP/MS.

Wipes of horizontal surfaces were collected on 8/28/00. Sample locations were selected in three areas; the kitchen outbuilding, the clubhouse, and the firing line. Sampling for surface contamination was conducted in accordance with procedures published by the U.S. Department of Housing and Urban Development (U.S. Department of Housing and Urban Development 1995). The only variation from the HUD method was the use of plastic bags as sample receptacles. The HUD procedure suggests the use of rigid receptacles that can be adequately rinsed prior to analysis. The sample digest method for the analysis of lead using these wipes samples is the HUD method and has been well documented (U.S. HUD 1990, 1995). The analysis of the digested wipe samples for lead by ICPMS has also been documented (Rich et. al. 1999). Rinsing will allow any residual lead, which has migrated from the sample media to the inner surface of the container after sampling, to be included in the analysis of a given sample. The plastic bags could not be rinsed prior to analysis. This may have resulted in an underestimate of the amount of lead present on horizontal surfaces and shooter's hands. Area wipes were prepared and analyzed using the procedure described in the proceeding paragraph for hand wipes. For this work, NIST Standard Reference Materials were included in each sample run and recoveries were calculated to be between 98 and 105% with an average recovery of 105% and a standard deviation of $\pm$ 5.5%.

IRB procedures for this level study were followed. The protocol did not require an IRB approval. The study was exempt, as no invasive procedures were performed and there were no unique identifiers for the subjects.

RESULTS AND DISCUSSION

Air testing results for the 8/29 competition revealed mean exposures of 286

$\mu g/m^3$and 579 $\mu g/m^3$ for the 22 caliber and center-fire portions, respectively. This data included information on one competitor who fired 45 caliber ammunition throughout the duration of the competition, and the investigator who did not fire a pistol during the competition. Paired t-testing was performed to examine the increase in exposure during the center-fire portion of the 8/22 competition. Data on the investigator and the competitor who fired 45 caliber ammunition throughout the competition were not included in the data set for the purposes of t testing. The increase in exposure during the center-fire portion of the 8/22 competition was found to be statistically significant ($P < 0.001$).

Air testing results from the 11/7 competition revealed mean exposures of 235 $\mu g/m^3$ and 1558 $\mu g/m^3$ for the 22-caliber and center-fire portions, respectively. This 6.6 fold increase in the mean exposure observed between the 22 caliber and center-fire portions of the 11/7 competition was found to be statistically significant using paired t-testing ($P < 0.001$).

The significant increase in exposure to airborne lead during the center-fire portion of both the 8/29 and 11/7 competitions may attributable the larger caliber ammunition used during those competitions. The center-fire portion of these competitions is typically completed using 45 caliber ammunition. This caliber change, from 22 to 45 caliber, results in an approximate doubling of bullet diameter and an increase in the amount of explosive primer compounds used. Primer compounds and the bullet itself are the primary sources of lead in ammunition (Dams et. al. 1988).

When caliber specific exposures to airborne lead recorded during the summer (8/29) and winter (11/7) competitions were compared, a significant ($P < 0.01$) increase was recorded during the center-fire portion of the 11/7 competition. The mean airborne exposure recorded during the center-fire portion of the 11/7 competition (1558 $\mu g/m^3$) was 170% higher than the mean airborne exposure recorded during the center-fire portion of the 8/29 competition (579 $\mu g/m^3$). This increase was probably due to the installation of the front wall prior to the 11/7 competition and an increase in the number of participants from 10, during the 8/29 competition, to 14, during the 11/7 competition. Assuming that the increase in exposure is proportional to the increase in the number 242 $\mu g/m^3$ and 235 $\mu g/m^3$, respectively. Comparison of the means was accomplished through t-testing (pooled and Satterthwaite analysis). Figure 3 summarizes the results of personal air sampling for the 8/29 and 11/7 competitions.

Results of personal air monitoring during both the 8/29 and 11/7 competitions revealed that the highest potential for exposure occurs during the center-fire portion of each competition. As stated above, the majority of competitors fire 45 caliber pistols during center-fire competition. The 11/20 competition was completed firing only specially designed "low-lead" 45 caliber ammunition. This ammunition consisted of a brass encased bullet and a lead/heavy metal-free primer. Low lead means that the ammunition is designed so that the actual lead bullet, including the base, is fully encased in brass and lead-free explosive primer compounds are used. Much of the lead emitted when bullets are fired is in the form of lead fume from hot bullets (which is reduced by the brass coating), and lead compounds emitted when primers explode (which is eliminated by using lead free primers). A dramatic decrease in exposures to airborne lead was realized during the 11/20 competition with 97% and 99% reductions in the mean lead exposure experienced during the center-fire portions of the 8/29 and 11/7 competitions, respectively (See Figure 4). Tripathi, et. al. (1991) noted similar effects when copper jacketed 38 caliber ammunition as substituted for standard 38 caliber ammunition at a covered outdoor firing range. The authors of this study noted 92% and 97% reductions in airborne lead levels measured during personal air sampling conducted on two firearms instructors. The most likely explanation for this decrease in exposure was the exclusive use of specially designed "low-lead" ammunition and a decrease in the number of participants (6) during the 11/20 competition. Assuming the decrease in mean exposure is proportional to the decrease in the number of shooters, reductions in the mean airborne lead exposure of 57% (11/7/99) and 40% (8/28/99) would have been expected during the 11/20 competition. After accounting for the decrease in the number of shooters during the 11/20 competition, reductions in the mean airborne lead exposure of 42% (11/7/99) and 57% (8/28/99) were realized. The most likely explanation for this reduction is the use of low-lead ammunition during the 11/20 competition.

It is also interesting to note that none of the hand wipes collected during the 11/20 competition returned quantities of lead that were distinguishable from background. Conversely, 90% and 97% of the hand wipes collected during the 8/29 and 11/7 competitions returned quantities of lead that exceeded background. This fact indicates that the use of low-lead ammunition during the 11/20 competition resulted not only in a reduction of airborne exposure, but also in a reduction in dermal exposure and the potential for subsequent ingestion due to hand-to-mouth contact.

In order to compare the exposure concentrations yielded by personal air sampling to OSHA Permissible Exposure Limits, we converted concentrations into estimates of total lead inhaled or lead dose. We used the method discussed by Stern (1996) to perform this conversion. This method consisted of the application of the following formula:

$$((ARR * ET) / 1000) * ER = \text{Lead Dose } (\mu g)$$

ARR = Average Respiratory Rate (assumed to be 20 liters per minute)
ET = Exposure Time (minutes)
ER = Exposure Rate ($\mu g/m^3$)

Mean lead doses for competitors were compared to the estimated lead dose received by an employee exposed at the OSHA permissible exposure limit (PEL) of 50 $\mu g/m^3$ for a period of 8 hours. When the formula given above is applied,

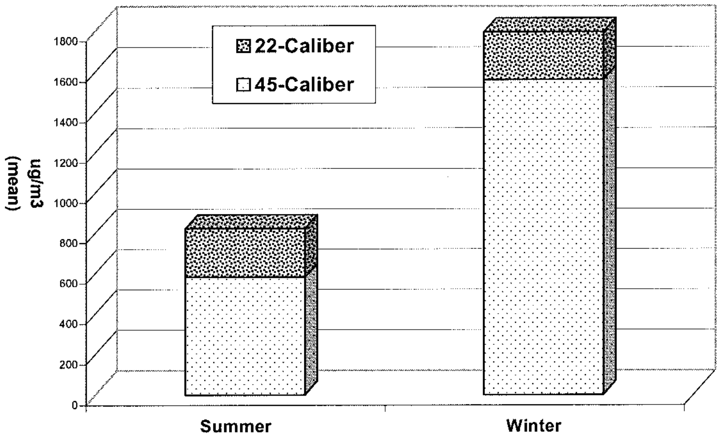

Figure 3. Personal air sampling results 8/29 (N = 10) and 11/7 (N = 9).

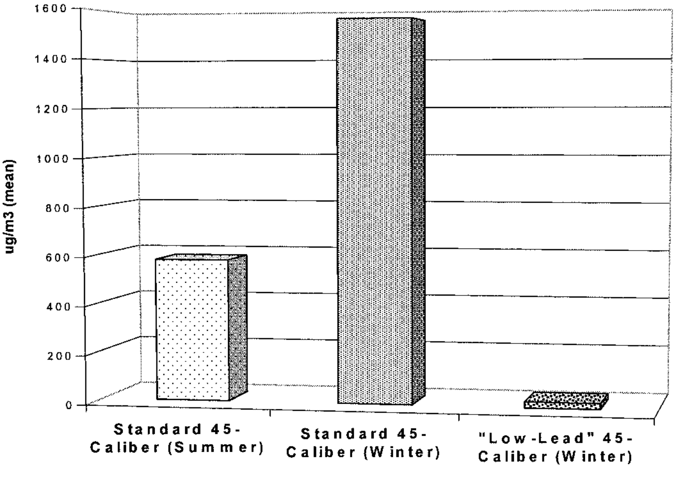

Figure 4. Mean air lead exposures recorded during the center-fire competitions on 8/29 (N = 10), 11/7 (N = 9), and 11/20 (N = 7).

this dose is calculated at 480 μg of lead. The mean lead doses measured during the 8/29 and 11/7 competitions were 2.3 (1104 μg) and 5 (2400 μg) times the 480 μg dose estimate for a maximally exposed OSHA employee, respectively. The mean lead exposure recorded during the 11/20 competition was 14 (34 μg) times lower than the 480 μg limit for a maximally exposed OSHA employee. As mentioned earlier, this dramatic decrease is most probably attributable to a decrease in the number of competitors during the 11/20 competition and the fact that low-lead 45 caliber ammunition was fired during the 11/20 competition.

Wipe results indicated that ingestion, via hand-to-mouth contact, was also a potential exposure pathway at this facility. Mean lead concentrations on horizontal surfaces were 328 $\mu g/ft^2$ and 3345 $\mu g/ft^2$ for the clubhouse and firing areas, respectively. The median mass of lead deposited on shooter hands during the 22 caliber portion of the 8/29 and 11/7 competitions was 233 μg and 50 μg, respectively. The median mass of lead deposited on shooter's hands during the center-fire portion of the 8/29 and 11/7 competitions were 324 μg and 353 μg, respectively. These results indicate that lead is deposited on shooter's hands during loading and firing activities.

Major suggestions to reduce exposure at this facility were to move the active exhaust intakes so that they are inside the firing area during the winter months, develop standard operating procedures for cleaning horizontal surfaces, and to reinforce hand washing and other good hygiene practices. The use of specially designed low-lead ammunition was proven to be effective in reducing airborne lead levels and deposits on shooter's hands, despite the presence of the front wall.

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