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PREFACE

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ACKNOWLEDGMENTS AND AVAILABILITY OF REPORT

This report was prepared by Michael E. Barsan and Aubrey Miller, M.D. of the Hazard Evaluations and Technical Assistance Branch, Division of Surveillance, Hazard Evaluations and Field Studies (DSHEFS). Desktop publishing by Ellen E. Blythe.

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Health Hazard Evaluation Report 91–0346–2572
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SUMMARY

In July 1991, the National Institute for Occupational Safety and Health (NIOSH) received a request for a Health Hazard Evaluation (HHE) from a management representative of the Federal Bureau of Investigation (FBI) at the FBI Academy in Quantico, Virginia. The request concerned lead exposures during firearms training and associated activities among range technicians, gunsmiths, and firing range instructors. Additionally, the requestor was concerned about the potential for "take-home" lead contamination of workers' vehicles and homes, and exposure of their families. Workers also expressed concerns about work-related noise-induced hearing loss.

In response to this request, NIOSH participated in a series of collaborative evaluations with the National Center for Environmental Health (NCEH). The following report concerns the NIOSH evaluation of lead exposures incurred by FBI employees during firearms training activities and associated use of the firing ranges, and a review of audiometric testing for noise-induced hearing loss.

In November and December 1991, NIOSH investigators conducted a walk-through survey of the FBI Firearms Training Unit (FTU) firing ranges and related facilities and conducted: (1) air sampling for lead, (2) qualitative evaluation of firing range ventilation systems using a smoke generator, (3) sampling of carpets for lead dust in student and non-student dormitory rooms (rooms used by visiting law enforcement officials not typically involved in firearms training), (4) medical interviews of FBI employees associated with the FTU, and (5) review of blood lead and audiometric testing results for current FTU workers.

The survey was designed to determine occupational lead exposures among FBI and Drug Enforcement Agency (DEA) firing range instructors, gunsmiths, range technicians, and custodians. Sixty-one personal breathing-zone (PBZ) and 30 area samples for airborne lead were collected. Personal sampling found that firing range instructors' exposures ranged up to 51.7 micrograms per cubic meter ($\mu g/m^3$) (mean 12.4 $\mu g/m^3$), range technicians' exposures ranged up to 2.7 $\mu g/m^3$ (mean 0.6 $\mu g/m^3$), and gunsmiths' exposures ranged up to 4.5 $\mu g/m^3$ (mean 0.6 $\mu g/m^3$). Custodians' exposures ranged from non-detectable to 220 $\mu g/m^3$ during short-term cleaning of a large indoor range.

Private medical interviews were conducted with 13 randomly selected workers (6 instructors, 2 range technicians, 2 gunsmiths, and 3 custodians) associated with the FBI FTU. None of the interviews were remarkable for any significant symptoms or health problems associated with the workplace lead exposures. Records of blood lead levels (BLLs) for all current FBI instructors, range technicians, gunsmiths, and custodians from 1989-1991 were reviewed. The mean BLL among instructors decreased from 14.6 micrograms per deciliter (µg/dl) in 1989 to 7.4 µg/dl in 1991. In comparison, there was no appreciable reduction in mean BLL among gunsmiths and range technicians during this time period. Custodians, who

were first tested in 1991, all had BLL of less than 4 µg/dl. Although the BLLs for workers were generally below the U.S. Public Health Service goal of 25 µg/dl[10] (only two were above 25 µg/dl), there are still potential adverse health effects that have been associated with BLLs similar to those found in FTU workers (i.e., small blood pressure elevations associated with lead levels as low as 10 µg/dl[7]).

A review of recent and baseline audiometric test results for 14 instructors and 1 range technician was performed. Nine of the 15 had audiometric abnormalities that met the OSHA Standard Threshold Shift criteria (i.e., changes relative to baseline of 10 dB or more in the average hearing level at 2000, 3000, and 4000 Hz).

Carpet dust samples were collected in 14 FBI student dormitory rooms (third floor of the student dormitory) and in 14 non–student dormitory rooms (second and third floor of an adjacent dormitory). Student dormitory rooms had significantly higher lead levels than non–student dormitory rooms (means of 214 and 65 µg respectively). This suggests that FBI students may be contaminating their living quarters with lead.

A potential hazard from short-term overexposure to lead via inhalation existed at the FBI Firearms Training Unit outdoor firing ranges at the time of the investigation. The direction of the prevailing wind at the outdoor ranges was found to influence the extent of lead exposure. In addition, a potential problem of "take-home" lead exposure of families of firearms instructors was found. Review of audiometric test results suggests that workers may be at increased risk for noise induced hearing loss. Recommendations for enhanced hearing protection, modifications of the indoor firing range's ventilation system, and for safe use of all the ranges are offered at the end of this report.

Keywords: SIC 9221 (Police Protection), indoor firing ranges, outdoor firing ranges, inorganic lead, ventilation system design, engineering controls, para-occupational exposure, blood lead level, noise, hearing loss

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INTRODUCTION

In July 1991, the National Institute for Occupational Safety and Health (NIOSH) received a request for a Health Hazard Evaluation (HHE) from a management representative of the Federal Bureau of Investigation (FBI) at the FBI Training Academy in Quantico, Virginia. NIOSH was requested to evaluate lead exposures during firearms training and associated activities among range technicians, gunsmiths, and firing range instructors. Additionally, the requestor was concerned about the potential for "take-home" lead contamination of workers' vehicles and homes, and exposure of their families.

In November and December 1991, NIOSH investigators conducted a walk-through survey of the FBI Firearms Training Unit (FTU) firing ranges and related facilities at the Academy. In December 1991, NIOSH investigators conducted an air-sampling survey to determine airborne lead exposure to the firing range personnel during their workday. Also during this survey, a smoke generator was used to evaluate the effectiveness of the ventilation system at the indoor firing ranges. A review of audiometric testing for noise-induced hearing loss was also conducted in response to employees’ concerns.

BACKGROUND

There were 16 full-time firearms instructors in the Firearms Training Unit (FTU) who spent an average of approximately 30 hours per week on the firing ranges. The instructors conducted firearms training sessions for the Federal Bureau of Investigation (FBI) and Drug Enforcement Agency (DEA) trainees at outdoor and indoor firing ranges. A second indoor range was used by gunsmiths to test-fire weapons. The FTU also included nine full–time gunsmiths who test-fired weapons, and five range technicians who handled ammunition. At the time of this investigation, there were eight trainee classes at the FBI Academy, composed of 32 students each. Each class goes through a 16–week training period during which there are 28 firearms training sessions. Firearms training sessions last about four hours. Hand washing facilities were available for the 16 current instructors (13 male and 3 female) in the FTU range office. However, shower facilities were available only for the male instructors. The instructors reportedly rarely used the shower and normally went home in the clothes that they wore at the firing ranges.

The FBI Academy had one indoor firing range that was used for training (Figure 1), one indoor range that was used for gun testing (Figure 1), and seven outdoor firing ranges that were used for training (Figure 2). The two indoor firing ranges were located on the first floor of a two–story, multi–use concrete block building. The training indoor firing range had 23 shooting booths for student training. Gunsmiths, instructors, and other FBI agents also used the range. The gun testing indoor range was large enough for just one shooter at a time. In this report, the larger firing range will be referred to as the "students' range," and the smaller range will be referred to as the "gunsmiths' range." The term "downrange" in this report means toward the bullet trap end of the range; "uprange" means toward the shooting end of the range. The directions "left" and "right" are relative to a shooter facing downrange.

Figure 1 shows that the right wall of the gunsmiths' range abutted the uprange wall of the students' range. The ranges had common supply and exhaust fans, and 100% of the range air was exhausted after one pass. The supply fan and air intake were adjacent to the left wall of the students' range. As it entered the building, supply air was pre–filtered by a 1–inch-thick filter mounted upstream of the rain louvers which covered the outside air intake. After pre–filtering, air entered a plenum, which was in the same room as the supply fan. This plenum contained a roll filter and heating coils, but there were no provisions for cooling the air. Both the pre–filter and roll filter were made of materials estimated to have a filter efficiency of less than 20%, according to the American Society of Heating, Ventilating, and Air–Conditioning Engineers (ASHRAE). After passing through the filters and heating coils in the plenum, the air entered the supply fan room and was distributed via ducts to the indoor ranges.

The exhaust fan system was separate from the supply fan system. The exhaust fan was in a room adjacent to the right side of the bullet trap area of the students' range. The room served as the fan plenum. Ducts from both indoor ranges ran through the walls of the room and terminated at the inside wall surface. These ducts were not directly connected to the exhaust fan, which removed air from the room through an exterior wall. Air was not filtered as it entered the exhaust fan room or before it was exhausted outside.

Students' Range

The students' range was approximately 100 feet by 100 feet and had 23 shooting booths. Due to structural columns uprange of the booths, there were gaps between booths 6 and 7, 13 and 14, and 20 and 21. There was an additional gap between Booth 1 and the left wall of the range. The ceiling height in the students' range was 7 feet for the area between the uprange wall and the firing line, and 8 feet for the first 10 feet downrange of the firing line. The ceiling height for the rest of the range was about 12 feet. Bullet deflectors, suspended from the ceiling downrange of the firing line, provided protection for lighting and ductwork. The range had double door entrances on each end of the uprange wall.

Air was supplied to the students' range through an uprange air wall, approximately 13 feet from the uprange end of the booths. This air wall was constructed of perforated metal panels mounted in an iron framework. The panels had a pattern of ¼–inch diameter holes on ½–inch vertical and horizontal centers, creating an approximate 15% free area of the wall (percentage of the total wall which is holes). The air wall was about 3 feet from the uprange endwall, creating a plenum in the space between the air wall and the end wall. Air was supplied to the air wall plenum through the ceiling via 23 branch ducts connected to a single main duct. Each duct opening had turning vanes mounted in the duct just upstream of the connection to the air wall plenum. Access to the air wall plenum was through a door in a room outside the gunsmiths' range. The entrances to the students' range were also air wall plenums. The outer doors of the entrances were metal–clad double doors, and the inner doors were double metal–frame doors with perforated metal panels that were the same design as the rest of the air wall. Each door plenum had a supply air branch duct in the ceiling that was connected to the same main duct supplying the rest of the air wall. The duct outlets had diffusers with moveable louvers.

The design air flow for the students' range was 43,900 cubic feet per minute (cfm). Average velocity through the booths using this flow rate, assuming a ceiling height of 8 feet and a room width of 100 feet, was approximately 55 feet per minute (fpm).

Exhaust air was removed from the range at two locations: approximately midway from the firing line to the bullet trap and at the bullet trap. Design air flow specifications were 8,000 cfm for the midrange exhaust and 40,000 cfm for the bullet trap exhaust. The midrange exhaust system consisted of ten 12-inch by 12-inch inlets approximately 10 feet above the floor. The inlets had single–blade dampers and hardware cloth covering the opening. The bullet trap exhaust consisted of twenty 18-inch by 18-inch inlets with single–blade dampers and hardware cloth coverings. The inlets for the trap exhaust system were directly above the trap.

The bullet trap was designed to direct spent bullets behind the trap. Spent bullets in the trap and lead impacted on the trap were cleaned manually. Access to the area behind the trap was through a door in the exhaust fan room.

Gunsmiths' Range

The gunsmiths' range was approximately 8 feet wide, 8 feet high, and 60 feet long. Instead of a shooting booth, there was a desk that is used when firing weapons. During firing, the gunsmith sat at the desk and rested his arms on a leather–covered weighted pillow which sat on a wooden box on the desk. The range had a single entrance through a door in the uprange wall. The downrange end of the desk was approximately 10 feet from the uprange wall.

Air was supplied to the gunsmiths' range through four in–line, ceiling mounted registers near the uprange endwall. Two of the registers were 2 feet by 2 feet, and the other two were 6 inches by 2 feet. All of the registers had opposed–blade dampers, and all but one had adjustable louvers. The registers covered nearly the entire width of the range.

The design exhaust flow for the gunsmiths' range was 4,050 cfm. Exhaust air was removed from the range by a single midrange exhaust and a single trap exhaust inlet similar in design to those in the students' range. The air flow distribution for the two inlets was not available.

Outdoor Ranges

Of the outdoor firing ranges, Fields 1, 2, and 3 were used most often by the FBI instructors. These three ranges were each about 100 yards wide by 60 yards long, with asphalt shooting lines at 7, 15, 25, 50, and 60 yards from the target line. The ranges were covered on three sides by dirt berms approximately 15 feet high. Each of these ranges could accommodate 80 shooters at one time. The electric range was about 45 yards wide by 25 yards long and had dirt berms similar to the other ranges. This range had moving targets and did not accommodate many shooters at one time. During this investigation, two students at a time used the electric range. Fields 1, 2, 3, and the electric range had a control tower in which one of the instructors sat during the firing session. In the control tower, the instructor used the public address system to give commands for shooting and operated the electric target holders.

The stress obstacle course (SOC) was approximately 100 yards long and could accommodate two shooters at one time. The two shooters traversed the course together, climbing obstacles and periodically shooting at steel targets located at various points along the course. The instructors walked along behind the shooters throughout the course. The SOC, which was located along the forest northwest of the other outdoor ranges, did not have dirt berms around it.

Custodians

There were three custodians responsible for cleaning the large indoor firing range about two times per week. This procedure consisted of using a dry broom to sweep the lead dust and other debris on the cement floor into piles downrange of the firing line. The piles were then collected using a high efficiency particulate air filter (HEPA) vacuum. The custodians also vacuumed the carpeting uprange of the firing line.

Lead Exposure Program

According to the present FBI policies, blood lead testing is performed every 6 months on all instructors, range technicians, and gunsmiths. Custodians, who were added to the blood lead testing program in 1991, undergo testing on an annual basis. All instructors are required to wear uniforms while working. However, instructors and range technicians are not required to routinely wear any specific protective clothing. Gunsmiths are provided protective aprons for routine use in the gun vault and indoor firing ranges. Custodians are required by the FBI to wear Tyvek™ suits with respiratory protection when performing any clean–up operations within the indoor firing range areas that had a significant potential for lead exposures, such as sweeping the downrange portion of the firing range.

EVALUATION DESIGN AND METHODS

Medical

Private medical interviews were conducted with 13 workers randomly selected from a list of 41 employees who worked in the indoor firing ranges and were available on the days of the survey. Six of the 16 FBI instructors, 2 of the 6 range technicians, 2 of the 13 gunsmiths, and 3 of the 6 custodians were interviewed. Information concerning possible health problems, symptoms associated with excess lead exposures, work practices, and use of personal protective equipment was gathered during the medical interviews. To determine the extent of workplace lead exposures, records of blood lead levels (BLLs) from 1989 - 1991 for the 41 current FBI instructors, range technicians, gunsmiths, and custodians were evaluated. Additionally, an evaluation for potential noise-induced hearing loss (NIHL) was conducted because of worker concerns about noise exposures during the firing of weapons. The NIHL evaluation included specific questioning of workers during medical interviews and a review of available baseline and most recent audiograms for instructors, range technicians, and gunsmiths. The blood lead and audiometric testing results were received and reviewed by NIOSH after the site visits.

Environmental

To assess lead exposures of firing range personnel (not students), personal breathing zone (PBZ) and area air samples for airborne lead were collected during seven different training sessions at six different firing ranges. At the outdoor ranges (Fields 1, 2, and 3, the electric range, and the SOC) PBZ air samples were collected from all the instructors, and area air samples were collected behind the firing line near the control tower. At the SOC, the area sample was collected near the beginning of the course.

To assess potential lead exposures to firing range personnel and effectiveness of the ventilation system in the indoor firing ranges, area air samples were collected throughout the range and in the ventilation system. Initially, air samples were collected while the ventilation system was running but the range was not in use. Air samples were then collected from the same locations with the ventilation system operating while the range was used for a firearms qualifying session. Because it was a qualifying session, we did not ask any of the shooters (FBI trainees) to wear personal sampling pumps. While the indoor range was being used for this qualification session, an area air sample was collected in the linen room adjacent to the firing range. During a different sampling period, a PBZ air sample was collected from a shooter using the indoor range for nearly 1½ hours. PBZ air samples were collected from three custodians during short-term cleaning (<1 hour) of the indoor range after it had been used for a few days. PBZ air samples were collected from all of the gunsmiths and range technicians for the entire day during each day of the survey.

All air samples were collected and analyzed according to NIOSH method 7300.[1] The analytical limit of detection (LOD) for lead on all of the air samples was 1.0 micrograms (µg) per sample, which equates to a minimum detectable concentration (MDC) of 2.9 micrograms per cubic meter (µg/m^3) for a 350–liter sample. The limit of quantitation (LOQ) for lead was 3.3 µg per sample, which equates to a minimum quantifiable concentration (MQC) of 9.4 µg/m^3 for a 350–liter sample.

Airflow patterns at the indoor firing range were observed using a Roscoe Fog Machine (model number 1500), which generated a visible, non–toxic "smoke." In the students' range, smoke was released in each of the 23 booths from the booth's shelf level and at the floor level directly beneath the shelf. In addition, smoke was released at the floor level in the gaps between booths 6 and 7, 13 and 14, and 20 and 21. In the gunsmiths' range, smoke was released on top of the desk and on the floor downrange of the desk.

At each position, the smoke was observed for about one minute to determine whether the air flowed through the booths and downrange as designed. Any back–flow through the booths and downrange was noted, and further testing was performed between the air wall and the booths, and downrange of the booths to identify the cause of any back–flow. This additional testing was performed at various non–specific distances and elevations.

Dormitory Room Lead Dust Evaluation

Since student trainees lived in the dormitory rooms during their 16-week training periods, it was expected the evaluation of room lead dust levels would show the potential for "take-home" lead contamination from FTU facilities to the private homes of FBI firearms instructors, gunsmiths, range technicians, and custodians. To assess the extent of lead contamination in the FBI student dormitory rooms, carpet dust samples were collected from the carpet in 14 student dormitory rooms (on the third floor of the student dormitory) and in 14 non–student dorm rooms (on the second and third floors of an adjacent dormitory). Non-students would not be likely to use the firing ranges. Samples were collected on mixed cellulose ester filters in cassettes connected to personal air sampling pumps calibrated to a flow rate of 2.0 liters per minute. The cassettes were connected to the pumps with a short piece of Tygon™ tubing. The collection attachment was a piece of stainless steel tubing crimped on one end to form an elongated opening.[2] Dust samples were collected from the area inside a 25 x 25 centimeter plexiglass template that was placed on the floor in the rooms. The samples were analyzed according to NIOSH method 7300.[1] Two samples were collected in each room: centered in the hallway door two feet inside the room, and adjacent to the center of the bathroom door.

EVALUATION CRITERIA

Lead

People have used lead since ancient times because of its useful properties, and it was the ancient Romans and Greeks who first discovered its toxic effects. Workplace exposure to lead occurs by inhalation of dust and fume and ingestion of lead-contaminated dust on surfaces. Once absorbed, lead accumulates in the soft tissues and bones. A person's BLL is the best indication of recent exposure to, and current absorption of lead. Lead is stored in the bones for decades, and health effects may occur long after the initial exposure as the bones release lead in the body.

Numerous studies have documented toxic effects of lead on the nervous system, reproductive system, kidneys, blood-forming system and the digestive system.[3,4,5,6,7] Lead has been shown to be an animal carcinogen, but there is not yet conclusive evidence that lead exposure causes cancer in humans. Lead poisoning can occur because of chronic exposure or after a short period of very high exposure. The frequency and severity of symptoms associated with lead exposure generally increase with the BLL. Many of the symptoms of excessive lead exposure can easily be confused with other causes; these include weakness, excessive tiredness, irritability, constipation, anorexia, abdominal discomfort (colic), and fine tremors.[3,4,5,6,7]

The Occupational Safety and Health Administration (OSHA) general industry lead standard (29 CFR 1910.1025 [1978]) established a Permissible Exposure Limit (PEL) of 50 $\mu g/m^3$ and an action level of 30 $\mu g/m^3$ (both 8-hour time–weighted averages [TWAs]).[8] The OSHA standard requires adjusting PEL for work shifts longer than 8 hours, medical monitoring for employees exposed to airborne lead at or above the action level, medical removal of employees whose average BLL is 50 micrograms per deciliter (µg/dl) or greater, and economic protection for medically removed workers. Medically removed workers cannot return to jobs involving lead exposure until their BLL is below 40 µg/dl. The American Conference of Governmental Industrial Hygienists (ACGIH) threshold limit value (TLV™) for lead is 50 $\mu g/m^3$ (8-hour TWA), with a BEI of 30 µg/dl. ACGIH has also designated lead as an *animal carcinogen* and recommends that "...worker exposures by all routes be carefully controlled to levels as low as possible below the TLV."[9] The U.S. Public Health Service has establish a national public health goal to eliminate all occupational exposures that result in BLLs greater than 25 µg/dl by the year 2000.[10] NIOSH supports the Public Health Service goal and recommends that to minimize the risk of adverse health effects, employers and workers should continually strive to reduce workplace lead exposures.

Health studies indicate that the OSHA lead standards noted above are not protective for all the known health effects of lead. Studies of adults have found neurological symptoms with BLLs of 40 to 60 µg/dl, decreased fertility in men at BLLs as low as 40 µg/dl, and increases in blood pressure with no apparent threshold to BLLs of less than 10 µg/dl.[7] Fetal exposure to lead is associated with reduced gestational age, birth weight, and early mental development with maternal BLLs as low as 10 to 15 µg/dl.[7]

Lead exposure reduction efforts over the past two decades in the U.S. have resulted in a significant drop in lead exposures. From 1976 and 1991 the mean adult BLL dropped from 13.1 to 3.0 µg/dl, and in 1991 more than 98 percent of adults had a BLL less than 15 µg/dl.[11] Occupational lead exposures of public health concern continue to occur, however. For example, in 1994 the NIOSH Adult Blood Lead Epidemiology and Surveillance program received reports for 12,137 adults with elevated BLLs $\geq$25 µg/dl from 23 participating states.

In homes with a family member occupationally exposed to lead, care must be taken to prevent "take home" of lead. Lead may be carried into the home on clothing, skin, or hair, or from vehicles. High BLLs in resident children, and elevated concentrations of lead in the house dust, have been found in the homes of lead-exposed workers.[12] Children of persons who work in areas of high lead exposure should receive a BLL test.

Lead in surface dust and soil

Lead is commonly found in U.S. urban dust and soil due to the past use of lead in gasoline and paints, and also industrial emissions. Lead-contaminated surface dust and soil represent potential sources of lead exposure, particularly for young children. Lead exposure may occur either by direct hand-to-mouth contact, or indirectly from hand-to-mouth contact with contaminated clothing, cigarettes, or food. Previous studies have found a significant correlation between resident children's BLLs and house dust lead levels.[13] There is no federal standard which provides a permissible limit for lead contamination of surfaces in occupational settings. As required by Section 403 of the Toxic Substances Control Act (as amended in 1992) the Environmental Protection Agency (EPA) is in the process of developing health-based residential standards for lead in dust, paint, and soil.

EPA currently recommends the following clearance levels for surface lead loading be met after residential lead abatement or interim control activities: uncarpeted floors, 100 micrograms per square foot ($\mu g/ft^2$); interior window sills, 500 $\mu g/ft^2$, and window wells, 800 $\mu g/ft^2$.[14] These levels have been established as achievable through lead abatement and interim control activities, and they are not based on projected health effects associated with specific surface dust levels.

EPA currently recommends a strategy of scaled responses to soil lead contamination, depending upon lead concentrations and site-specific factors. When lead concentrations exceed 400 ppm in bare soil, EPA recommends further evaluation and exposure reduction activities be undertaken, appropriate to the site-specific level of risk. If soil lead concentrations exceed 5000 ppm, EPA recommends permanent abatement of contaminated soil.[14]

Lead–childhood exposure

The adverse effects of lead on children and fetuses include decreases in intelligence and brain development, developmental delays, behavioral disturbances, decreased stature, anemia, decreased gestational weight and age, and miscarriage or stillbirth. Lead exposure is especially devastating to fetuses and young children due to potentially irreversible toxic effects on the developing brain and nervous system.[7]

No threshold has been identified for the harmful effects of lead in children; the Centers for Disease Control and Prevention (CDC) currently recommends a multitier approach to defining and preventing childhood lead poisoning, based on BLL screening.[15] The BLLs and corresponding actions which CDC has recommended are: $\geq$10 μg/dl, community prevention activities; $\geq$15 μg/dl, individual case management including nutritional and educational interventions and more frequent screening; $\geq$20 μg/dl, medical evaluation, environmental investigation and remediation. Additionally, environmental investigation and remediation are recommended for BLLs of 15–19, if such levels persist.

Overall, U.S. population blood lead levels have declined since 1976. A recent national survey found that the geometric mean BLL for children ages 1–11 ranged from 2.5–4.1 μg/dl, with the highest mean BLL among children aged 1–2 years.[16] However, it was estimated from the survey that 8.9% of U.S. children under 6 years, or about 1.7 million children, have elevated BLLs ($\geq$ 10 μg/dl).

Ventilation Principles for Evaluation of Indoor Firing Ranges

Ideally, the air flow in indoor firing ranges should be laminar and horizontal from the air wall to downrange of the booths. A horizontal, laminar air flow pattern will carry contaminated air away from the shooter toward the exhaust system. A moderate rise in the direction of air movement between the air wall and the booths is tolerable, as long as eddies which cause back–flow through the booths do not occur. Air which flows back from downrange through the booths is undesirable because back–flowing air could recirculate lead fume from downrange to the shooter's breathing zone. Shooters can be exposed to lead fume in the back–flowing air even after shooting has stopped.

Noise Induced Hearing Loss (NIHL)

Noise-induced loss of hearing is an irreversible, sensorineural condition that progresses with exposure. Although hearing ability declines with age (presbycusis) in all populations, exposure to noise produces hearing loss greater than that resulting from the natural aging process. This noise-induced loss is caused by damage to nerve cells of the inner ear (cochlea) and, unlike some conductive hearing disorders, cannot be treated medically.[17] While loss of hearing may result from a single exposure to a very brief impulse noise or explosion, such traumatic losses are rare. In most cases, noise-induced hearing loss is insidious. Typically, it begins to develop at 4000 or 6000 Hertz (Hz) (the hearing range is 20 Hz to 20000 Hz) and spreads to lower and higher frequencies. Often, material impairment has occurred before the condition is clearly recognized. Such impairment is usually severe enough to permanently affect a person's ability to hear and understand speech under everyday conditions. Although the primary frequencies of human speech range from 200 Hz to 2000 Hz, research has shown that the consonant sounds, which enable people to distinguish words such as "fish" from "fist," have still higher frequency components.[18]

The A-weighted decibel [dB(A)] is the preferred unit for measuring sound levels to assess worker noise exposures. The decibel unit is dimensionless, and represents the logarithmic relationship of the measured sound pressure level to an arbitrary reference sound pressure (20 micropascals, the normal threshold of human hearing at a frequency of 1000 Hz). Decibel units are used because of the very large range of sound pressure levels which are audible to the human ear. The dB(A) scale is weighted to approximate the sensory response of the human ear to sound frequencies. Because the dB(A) scale is logarithmic, increases of 3 dBA, 10 dBA, and 20 dBA represent a doubling, tenfold increase, and 100-fold increase of sound energy, respectively. It should be noted that noise exposures expressed in decibels cannot be averaged by taking the simple arithmetic mean.

The OSHA standard for occupational exposure to noise (29 CFR 1910.95)[19] specifies a maximum PEL of 90 dB(A)-slow response for a duration of eight hours per day. The regulation, in calculating the PEL, uses a 5 dB time/intensity trading relationship, or exchange rate. This means that when a person is exposed to noise levels of 95 dB(A), the amount of time allowed at this exposure level must be cut in half in order to be within OSHA's PEL. Conversely, a person exposed to 85 dB(A) is allowed twice as much time at this level (16 hours) and is within his daily PEL. NIOSH, in its Criteria for a Recommended Standard,[20] proposed an exposure limit of 85 dB(A) for 8 hours, 5 dB less than the OSHA standard. The NIOSH 1972 criteria document also used a 5 dB time/intensity trading relationship in calculating exposure limits. However, NIOSH changed its official recommendation for an exchange rate of 5 dB to 3 dB in 1995.[21] The ACGIH also changed its TLV in 1994 to a more protective 85 dB(A) for an 8-hour exposure, with the stipulation that a 3 dB exchange rate be used to calculate time-varying noise exposures.[22] Thus, a worker can be exposed to 85 dB(A) for 8 hours, but to only 88 dB(A) for 4 hours or 91 dB(A) for 2 hours.

Time-weighted average (TWA) noise limits as a function of exposure duration are shown as follows:

Duration of Exposure (hrs/day)	Sound Level dB(A)	
	ACGIH / NIOSH	OSHA
16	82	85
8	85	90
4	88	95
2	91	100
1	94	105
1/2	97	110
1/4	100	115*
1/8	103	---
1/16	106	
1/32	109	
1/64	112	
1/128	115*	
	***	**

* No exposure to continuous or intermittent noise in excess of 115 dB(A).
** Exposure to impulsive or impact noise should not exceed 140 dB peak sound pressure level.
*** No exposure to continuous, intermittent, or impact noise in excess of a peak C-weighted level of 140 dB.

The duration and sound level intensities can be combined to calculate a worker's daily noise dose according to the formula:

Dose = 100 X (C1/T1 + C2/T2 + ... + Cn/Tn),

where Cn indicates the total time of exposure at a specific noise level and Tn indicates the reference duration for that level as given in the above table. During any 24-hour period, a worker is allowed up to 100% of his daily noise dose. Doses greater than 100% are in excess of the evaluation criteria.

The OSHA regulation has an additional action level (AL) of 85 dB(A) which stipulates that an employer shall administer a continuing, effective hearing conservation program when the TWA value exceeds the AL. The program must include monitoring, employee notification, observation, an audiometric testing program, hearing protectors, training programs, and recordkeeping requirements. All of these stipulations are included in 29 CFR 1910.95, paragraphs (c) through (o).

The OSHA noise standard also states that when workers are exposed to noise levels in excess of the OSHA PEL of 90 dB(A), feasible engineering or administrative controls shall be implemented to reduce the workers' exposure levels. Also, a continuing, effective hearing conservation program shall be implemented.

RESULTS

Medical Results

Medical Interviews

Private medical interviews were conducted with 13 FBI employees (6 instructors, 3 custodians, 2 gunsmiths, and 2 range technicians). Of those interviewed, five of the six instructors and all gunsmiths and range technicians were male. All three of the interviewed custodians were female. The instructors were older than the other worker groups, with an average age of 44 years (range 38–48), versus an average age of 38 years (range 30–44) for the other work groups combined. Compared to other groups, instructors were also employed longer at the FBI, averaging 13 years, while the other work groups combined averaged 4 years. Only two of the interviewed workers (both gunsmiths) reported any notable history of non–work related lead exposures.

Medical interviews revealed only complaints of occasional headaches experienced by two instructors when firing guns on the indoor ranges. None of the interviewed employees reported any recent or past history of symptoms associated with their jobs, including any symptoms which might be associated with elevated lead exposures. While none of the workers reported any history of work-related symptoms, a number of workers expressed concerns about NIHL and reproductive problems potentially related to their occupational exposures. All interviewed gunsmiths voiced concern about potential lead exposures during routine unprotected cleaning and sweeping of the small indoor firing range.

The average reported durations of potential occupational exposure to lead differed among the work groups. The average reported periods of potential work-related lead exposures were approximately 22 hours per week (5 hours per day) for instructors and gunsmiths, 16 hours per week (3 hours per day) for range technicians, and 6 hours per week (1 hour per day) for custodians. Of the 13 workers interviewed, 31% (4) reported eating or drinking and 15% (2) reported smoking, in areas (i.e., indoor ranges, weapon cleaning areas) with potential lead exposures. Seventy-seven percent (10) of the interviewed workers reported that they consistently washed their hands after lead exposures, and 15% (2) reported showering at work prior to going home. All instructors reported wearing uniforms between home and work and laundering their uniforms at home. Gunsmiths and range technicians all reported wearing aprons or coveralls over their street clothes while working and frequently washed these protective clothes at home. Custodians reported wearing full length Tyvek™ suits during clean-up of all indoor firing ranges and disposing of the suits prior to leaving the area. All workers reported wearing eye and hearing protection when firing weapons or working near active firing ranges.

Blood Lead Testing Program

Table 1 summarizes the 1989—1991 BLL results of the 41 workers (instructors, range technicians, gunsmiths, and custodians) employed at the time of the NIOSH evaluation. Evaluation of blood lead test results for instructors and gunsmiths revealed a marked increase in the number of workers who participated in the BLL testing program from 1990 to 1991. Only six instructors underwent annual BLL testing in both 1990 and 1991. The mean BLL among these six instructors fell from 13.5 to 7.7 µg/dl. In comparison, there was no appreciable reduction in BLLs among gunsmiths and range technicians during this time period. As of 1991, the mean BLL of gunsmiths continued to be about 12 µg/dl. As of 1991, the mean BLL of range technicians was 13.6 µg/dl, and all custodians, who were first tested in 1991, had BLLs of less than 4 µg/dl.

Hearing Conservation (Audiometric Testing) Program

The baseline and the most recent audiometric testing results were available for 14 of the 16 current FBI instructors. Evaluation of these audiograms revealed hearing losses that met the OSHA Standard Threshold Shift (STS) criterion (i.e., changes relative to baseline of 10 dB or more in the average hearing level at 2000, 3000, and 4000 Hz) in 64% (9 of 14) of the instructors tested. Audiometric testing results were only available for one of the six current range technicians, and this worker's results also met the OSHA STS criterion. There were no complete sets of recent and baseline audiometric testing results for the gunsmiths currently employed in the FTU.

Environmental Sampling Results

Lead Exposure Assessment

Outdoor Firing Ranges

Presented in Table 2 are the results of PBZ and area air sampling results for airborne lead collected at Field 2, an outdoor range, during a 4–hour training session. The only sample that contained a detectable amount of lead (5.1 $\mu g/m^3$) was the PBZ sample for FBI Instructor C. Lead was not detected on the PBZ sample for the control tower operator (FBI Instructor F). Wind direction during this session was predominantly downrange.

Table 3 presents the results of PBZ and area air sampling for airborne lead at Field 2 during a 3–hour training session. The only sample on which lead was not detected was for FBI Instructor D, who was in the control tower for the duration of the training session. Airborne PBZ lead concentrations for the instructors at the firing line ranged from 15.2 to 51.7 $\mu g/m^3$ (mean 30.7 $\mu g/m^3$). The area sample for this training session was collected next to a telephone pole near the control tower. This sample revealed an airborne lead concentration of 2.4 $\mu g/m^3$. Wind direction during this session was variable, with no clearly predominant wind direction.

Presented in Table 4 are the results of PBZ and area air sampling for airborne lead during a 3½–hour training session at Field 1. The only sample on which lead was not detected was for FBI Instructor M, who was in the control tower for the duration of the training session. Airborne PBZ lead concentrations for the instructors at the firing line ranged from 5.1 to 10.0 $\mu g/m^3$ with a mean of 6.8 $\mu g/m^3$. The area sample for this training session was collected next to a telephone pole near the control tower. This sample revealed an airborne lead concentration of 2.0 $\mu g/m^3$. Wind direction during this session was variable, with no clearly predominant wind direction.

Table 5 presents the results of PBZ and area air sampling for airborne lead at Field 3 during a 3–hour training session. The only sample on which lead was not detected was for the area sample, which was collected next to a telephone pole near the control tower. Airborne PBZ lead concentrations for the DEA Instructors at the firing line ranged from 6.0 to 17.4 $\mu g/m^3$ with a mean of 11.5 $\mu g/m^3$. Wind direction during this session was variable, with no clearly predominant wind direction.

Table 6 presents the results of PBZ and area air sampling for lead at the Electric Range and at the SOC. At the Electric Range, lead was detected on only one of the FBI Instructor's PBZ samples, giving an airborne lead concentration of 4.9 $\mu g/m^3$. The other instructor at the Electric Range (FBI Instructor N) was in the control tower for the duration of the training session. The PBZ airborne lead concentrations for the two FBI instructors at the SOC were 29.8 and 30.2 $\mu g/m^3$. Lead was not detected on the area sample at the SOC, which was collected behind the start of the course. During the session at the Electric Range, wind direction was predominantly downrange; wind direction measurements were not available from the SOC.

Indoor Firing Ranges

Table 7 presents the results of area air samples collected at the students' firing range. Samples were collected just outside the air intake of the indoor range, just inside the intake, in the intake plenum, and behind the pegboard through which air passes to enter the firing range. In the range itself, area air samples were collected on the control table, at two of the firing stations (#14 and #17), and at one of the down–range pillars. Two other area air samples were collected in the room that houses the exhaust fan which pulls range air outside the building, and outside the building near the exhaust air grates.

The top half of Table 7 presents results from air samples collected at the locations described above while the range was not in use. The bottom half of Table 7 presents results of air samples collected from these same locations while the range was being used for a qualification shooting session. Lead was detected in the exhaust fan room and just outside the exhaust vent during the sampling period in which the range was not in use. These concentrations were 2.8 and 22.7 $\mu g/m^3$, respectively. During the sampling period while the range was in use, airborne lead concentrations in the exhaust fan room and just outside the exhaust vent rose to 338.2 and 186.6 $\mu g/m^3$, respectively. During the latter session, an airborne lead concentration of 145.1 $\mu g/m^3$ was measured at a pillar downrange of the firing line. Lead was not detected on any of the other samples collected in the range or the ventilation system during either of these two sample periods. The range ventilation system was operating during both sampling periods.

Presented in Table 8 are the results of PBZ air samples for lead collected from the range technicians on two different days; low exposures were detected (2.2, 2.6, and 2.7 $\mu g/m^3$).

Table 9 presents the results of PBZ air samples for lead collected from the Gunsmiths during two different days. Also presented are area sample results that were collected just above the firing table in the gunsmiths' firing range. On the first day of sampling, lead was detected on just three of the nine PBZ air samples, showing concentrations of 2.0, 3.8, and 4.5 $\mu g/m^3$. On the second day, lead was detected on only one PBZ sample, revealing an airborne concentration of 1.1 $\mu g/m^3$. The area air sample in the gunsmiths' firing range showed an airborne lead concentration of 4.6 $\mu g/m^3$ on the first day, and 1.0 $\mu g/m^3$ on the second day.

Table 10 presents PBZ air sampling results for a FBI Hostage Rescue Team (HRT) agent who fired 182 rounds in the Students' Indoor Range during a period of about 1½ hours. Throughout the same day, including the HRT agent's firing session, an area sample for airborne lead was collected in the linen room adjacent to the firing range and the exhaust fan room. Lead was not detected on either the PBZ or the area sample.

Presented in Table 11 are results of PBZ sampling for airborne lead collected from three Custodians who cleaned the Students' Indoor Range for nearly an hour. The airborne lead concentrations for Custodians A and B were 127.5 and 220.0 $\mu g/m^3$, respectively. Custodian B used a dry push–broom to sweep debris into a pile, and Custodian A used a high efficiency particulate air (HEPA) vacuum to remove the debris. Lead was not detected on the PBZ sample for Custodian C, who vacuumed the carpet behind the firing line.

Lead was not detected on any of the field blanks collected for quality control purposes during this evaluation.

Qualitative Ventilation Assessment

Students' Indoor Range

Observations made while using the smoke generator revealed horizontal air movement with no back–flow in 12 shooting booths (2, 3, 4, 5, 10, 11, 16, 17, 18, 19, 20, and 21), while six booths (1, 6, 7, 8, 9, and

12) had irregular air movement across the upper part of the booths, with little to no backflow. The air flow tests revealed that with a person posing in a standing shooting position in a booth, the shooter's wake could induce contaminated air into the breathing zone. Increased laminar air flow through these booths with improved top-to-bottom distribution of the air should provide more even air flow across the entire booth cross section, which would reduce irregular air movement and improve ventilation efficiency.

Minor back–flow occurred at three booths (13, 14, and 15), and between booths 13 and 14 at ceiling level. Smoke released in the booths moved downrange and rose to the ceiling a few feet downrange. Intermittently, this downrange smoke would flow back along the ceiling across the firing line a few feet behind the shooters. The smoke then moved through the same booths and was drawn downrange.

Smoke testing uprange of the booths revealed that air exiting the air wall tended to move toward the right instead of moving straight downrange, creating a horizontal eddy behind the line. The intermittent nature of the back–flow in the booths could be caused by this eddy. A probable explanation for the movement of air exiting the air wall is that the plenum behind the air wall was used for storage of various boxed materials. Some of the boxes were stacked within six inches of the plenum perforated wall. Also, one of the plenum supply ducts did not have turning vanes to direct supply air. The missing vanes could affect the air flow pattern behind the wall and possibly the air flow distribution for all of the supply ducts. The materials inside the plenum and the possible uneven supply air flow distribution could affect the distribution and pattern of air coming from the air wall into the range.

Minor back–flow occurred through the upper section of booths 22 and 23, with air traveling back as far as the double doors directly uprange of these booths and then returning through the booth. Smoke tests uprange of the booths showed that the back–flow was mainly caused by the air flow distribution inside the door plenum. The louvers on the diffuser in this plenum directed air straight toward the floor. The air that impinged on the floor jetted along the floor through the perforated panel door toward the booths. This jet of air created a vertical eddy behind booths 22 and 23, which caused the back–flow through the booths. Also, cardboard targets had been stored in the plenum behind the air wall. When these were removed the back–flow lessened. The air distribution problem in the door plenum was the major cause of the back–flow through these booths.

Some of the area uprange of the firing line was used for storage of a few large items, including two large bins and a pallet of cardboard target backings. In addition, the control console was located on a desk that was equipped with a vanity panel, uprange of booths 12 and 13. Other range equipment and furniture were located in the area uprange of the booths. Even though smoke tests did not show that any of these items affected air flow through the booths, correction of the current air flow distribution problems may cause the obstructions to create new problems. Moreover, proper practice dictates that obstructions to the air flow uprange of the booths be minimized.

Gunsmiths' Indoor Range

There was no back–flow when smoke was released on top of the desk in this range. However, smoke released at the floor level flowed back to the desk from as much as ten feet downrange of the desk. Back–flowing air rose at the downrange end of the desk, but air moving across the top of the desk pulled the back–flow air downrange. Separate smoke tests with two people simulating firing positions at the desk showed that back–flowing air could enter the shooter's breathing zone. As in the students' range, removal of obstructions to the air flow would reduce or eliminate the back–flow.

Although the gunsmiths' range was found to be under negative pressure, design drawings showed that the supply and exhaust air flows were equal. To ensure that airborne lead dust does not escape the range, it should have a greater exhaust than supply air flow, placing the range under negative pressure.

Exhaust Fan Room

The current exhaust fan room does not function as effectively as a built–up plenum because control of leaks is difficult. Some of these leaks can affect the pressurization, and thus the related thermal and ventilation control of the ranges. In addition, opening the door of the exhaust fan room while the fan is running is difficult and unsafe. Leaks in the room also directly affect the volume of air exhausted from the ranges and, in turn, control of the contaminants in the range. Maintenance functions in the room are hazardous because all of the interior surfaces of the room were covered with lead dust. This dust could be spread through the building by inadvertent pressurization of the room, or by personnel carrying the dust into the building on clothing or shoes. Air is not filtered before being exhausted from the room to the outside.

Linen Room

The fact that lead was not detected on the area air sample collected in the linen room, which is adjacent to the indoor range and which is connected to the exhaust fan room, indicates that the airborne lead concentration in the linen room during the sampling period was less than 1 $\mu g/m^3$. Although it is very likely that lead is transported into the linen room on the shoes and clothing of people exiting the exhaust fan room, this is not likely to result in high airborne lead concentrations. If the exhaust fan room were to become positively pressurized with respect to the linen room, the result would be that lead dust in the exhaust fan room would enter the linen room.

Dormitory Room Lead Dust Sampling

Results of the carpet dust sampling collected in 14 dormitory rooms that were used by FBI students, and in 14 rooms that were used by non-students are presented in Table 12. The non-student rooms were used by various visitors to the FBI Academy who would not typically be using the firing ranges in the course of their activities. The lead concentrations are given in micrograms of lead per gram of carpet dust ($\mu g/g$). The total sample concentrations ranged from 116 to 546 $\mu g/g$ with a geometric mean of 214 for the students' rooms, while the non–student rooms ranged from 50 to 188 $\mu g/g$ with a geometric mean of 65. A two-tailed t-test was performed on the data from these rooms; the students' rooms had significantly higher lead levels than the non–student dorm rooms ($p < 0.0005$).

DISCUSSION

Lead

BLL test results from 1989 to 1991 for range technicians, gunsmiths, and instructors showed consistent BLL elevations in comparison to the entire US adult population (geometric mean of 3.0 $\mu g/dl$) from 1988 to 1991.[11] These results are consistent with low-level occupational exposure to lead. Exposures are probably due to a combination of skin contamination (not measured) with subsequent ingestion, chronic low-level airborne exposure, and occasional short-term high airborne lead exposure. Although none of the workers' BLLs exceeded the OSHA lead standard and were generally below the U.S. Public Health Service goal of 25 $\mu g/dl$[10] (only two were above 25 $\mu g/dl$), there are still potential adverse health effects that have been associated with BLLs similar to those found in FTU workers (i.e., small blood pressure elevations associated with lead levels as low as 10 $\mu g/dl$[7]). Of note, BLLs for instructors indicated that their lead exposures have been reduced over time, but those of range technicians and gunsmiths, have not (Table 1). Some of the instructors reported that the reduction in their BLLs was due to increased awareness of lead hazards and subsequent modification of work practices to reduce lead exposures. No specific information was available to substantiate these reports.

Custodians were found to have high short-term airborne exposures to lead during sweeping and vacuuming of an indoor firing range. However, they all had low 1991 BLLs (below 4 µg/dl). The custodians' low BLLs are probably primarily due to the fact that high exposure tasks were only performed infrequently, for short time periods.

NIOSH and the National Center for Environmental Health (NCEH), in a separate evaluation, found that vehicles of FTU workers and student dormitory rooms had elevated environmental lead levels, as compared with controls. These findings indicate the potential for take-home of workplace lead exposures. Lead contamination of workers' homes can lead to additional lead exposures outside of the workplace, for both workers and their families, and underscores the need for good hygiene practices (i.e., hand washing, changing clothes, showering) to reduce this potential exposure.

Noise

Sixty–four percent (9 of 14) of the current instructors and one range technician had audiometric changes relative to baseline of 10 dB or more in the average hearing level at 2000, 3000, and 4000 Hz (an OSHA-defined STS). Generally, in normal hearing, the sound sensitivity or threshold should be below 25 dB at 1000, 2000, and 3000 Hz. The normal pattern seen on audiograms in cases of NIHL is a reduction in sensitivity from about 2000 to 4000 Hz, with recovery between 4000 to 8000 Hz. Gunfire NIHL losses are most significant at 4000 Hz, which was consistent with the findings seen on audiograms of FTU workers. However, it is not possible to determine whether the abnormalities found in FTU workers were entirely due to NIHL, because high frequency data (above 4000 Hz) were missing on many of the tests.

In a previous study conducted by NIOSH researchers on U.S. Secret Service Agents;[23] researchers found that shooters who wore ear muffs and improperly inserted ear plugs experienced small positive temporary threshold shifts (TTS) at 6000 Hz when compared to shooters who wore ear muffs and properly inserted ear plugs. As a result of these findings, the NIOSH investigators concluded that when both the earmuffs and properly inserted earplugs are worn together, shooters receive adequate protection from gunfire noise so that it should not pose a considerable risk to hearing, provided that the shooter has no other substantial noise burden during the same 24-hour period. The FBI FTU workers typically wear only ear muffs during shooting sessions. The use of ear muffs only, while not studied during the secret service evaluation, most likely affords even less hearing protection than ear muffs and improperly inserted ear plugs. Therefore, FTU workers, and others exposed to gunfire, who wear only ear muffs may be at increased risk for NIHL.

Another issue of potential concern are findings that lead may be toxic to auditory centers of the brain.[24] In one study of 3,545 subjects aged 6–19 years, BLLs of even less than 10 µg/dl were found to be associated with an increased risk of hearing impairment.[25] While little is presently known about the combined effects of lead and noise on hearing, it would be prudent to provide maximal hearing protection to all workers with noise and lead exposures.

Instructors

Outdoor Ranges

PBZ airborne lead concentrations for the firing range instructors at the outdoor firing ranges were shown to be highly variable (range: <3.0 $\mu g/m^3$ to 51.7 $\mu g/m^3$). The highest air concentrations were measured during a training session at Field 2 (Table 3). During this session, the trainees fired 1024 rounds with 12–gauge shotguns and 5760 rounds using 9–millimeter handguns. During a different session at Field 2 (Table 1), the trainees fired nearly the same number of rounds, using identical weapons and ammunition, but the exposures were lower. The wind direction was predominantly downrange during the course of the latter training session. During the first session (Table 2), which was on a different day, the variable wind direction seemed to be less effective at removing airborne lead from the breathing zones of people near the firing line. Results from other sessions show similar variability in PBZ lead concentrations. Wind direction and speed affect the degree to which shooters and instructors are exposed to airborne lead at the firing line.

The airborne concentration of lead measured from one of the FBI instructors (sample 105, Table 2) was 51.7 µg/m^3 for a 174 minute sample, which would result in an 8-hour TWA of 18.8 µg/m^3. This is below the OSHA PEL of 50 µg/m^3 (8–hour TWA) and the action level of 30 µg/m^3. However, this concentration and the other relatively high lead concentrations presented in Tables 2 and 5 demonstrate that the potential exists for firing range instructors to have short-term exposures >50 µg/m^3.

Indoor Ranges

Air samples collected in the students' range demonstrate that the ventilation effectively carried airborne contaminants downrange, away from the shooters and instructors. Airborne lead concentrations in the exhaust fan room and just outside the exhaust vent increased dramatically during the second sampling period. This was due to the increased amount of airborne lead fume and particulate that was generated during the shooting session. Samples 44, 45, 51, and 52 were collected in the range behind the firing line at various points indicated in Table 6 and shown on Figure 1. The fact that lead was not detected on any of these samples indicates that the air flow pattern in the range was effective in moving airborne contaminants downrange. The minimum detectable concentration for an 80–minute sample period, similar to the duration of the sampling period for the samples collected behind the firing line, would be about 5 µg/m^3. This means that airborne concentrations in the sample locations behind the firing line during the shooting session were less than 5 µg/m^3.

Range Technicians

PBZ air sample results showed that the Range Technicians were exposed to very low levels of airborne lead during the two days of sampling (range: <2.1 µg/m^3 to 2.7 µg/m^3). The Range Technicians do not often work near the firing line during a shooting session, or elsewhere where high airborne lead concentrations would be expected. Since these workers are responsible for maintaining and repairing the ranges, and for supplying all of the ammunition, it is likely that their main source of lead exposure would be through skin contact and subsequent ingestion. Hand wipes were not collected from these workers.

Gunsmiths

The variability of PBZ air sample results from the gunsmiths (range: <1.1 µg/m^3 to 4.5 µg/m^3) occurred because not all of the gunsmiths fired weapons during the sampling period. All four gunsmiths with detectable personal lead exposures test–fired a weapon in the gunsmiths' range during the sampling period. The area samples, collected at the firing table in the gunsmiths' range reflect airborne lead concentrations very similar to those in the PBZ samples for the gunsmiths who fired weapons. The primary source of airborne lead exposure for the gunsmiths is the test–firing of weapons. Although hand wipes to identify dermal lead exposure were not collected from these workers, a portion of their total lead exposure probably arises from skin contact with lead while repairing weapons.

Custodians

Results of PBZ air samples collected from the Custodians who clean the students' range indicate that they can be exposed to high short-term concentrations of airborne lead (range: <10.0 µg/m^3 to 220 µg/m^3) during sweeping and vacuuming downrange of the firing line. Assuming that Custodian B encountered no other airborne lead exposure for the rest of the day, that worker's 8–hour TWA for the day would be 22.9 µg/m^3. This is below the OSHA action level of 30 µg/m^3, but it is still a source of lead exposure. Custodians A and B wore Tyvek™ clothing and half–mask respirators with HEPA filters while they cleaned the range. However, these respirators did not appear to fit them properly.

RECOMMENDATIONS

The following recommendations are made to assist the FBI in reducing employee exposures to lead, to improve medical surveillance of lead-exposed workers, and to reduce the potential for NIHL:

1. Food, beverages, tobacco products, and cosmetics should not be used, carried into, or stored in the firing ranges or in adjacent areas where lead exposures may occur. All personnel exposed to lead in the firing ranges should wash their hands and faces before eating, drinking, smoking, or having hand contact with other people. Washing should occur after shooting, handling fired cartridge cases, and cleaning weapons. These practices will reduce the potential for lead exposure by ingestion.

2. After shooting or maintenance work in the firing range, individuals should shower and change clothes. Employees should be provided with both "clean" and "dirty" storage lockers to allow them to separate street clothes from lead-contaminated work clothes.

3. Shooters using a kneeling or prone position over lead contaminated surfaces should place a sheet of heavy paper on the ground beneath them. The paper should be large enough to cover any area contacted by the shooter. This would reduce the amount of settled lead containing dust that is transferred to the shooter's clothing. Additionally, shooting time in the kneeling and especially the prone position should be limited.

4. Non–lead or copper–jacketed bullets should be used whenever possible because they have been shown to reduce lead emissions. Substituting copper–jacketed, nylon–jacketed, or zinc slugs has been shown to result in significant reduction in lead emission compared with traditional lead ammunition.[26] There will still be, however, some lead generated from the primer, which contains lead styphnate and lead peroxide. Ideally, non–lead bullets using non–lead primers should be used.

5. The firing range ventilation system should be in operation at all times while the range is in use and during clean–up.

6. After each use, the floor of the indoor firing range should be thoroughly cleaned with a HEPA vacuum designed to collect lead dust. Dry sweeping should never be used in the range. The vacuum should have a plastic bag liner, and a non–evaporating liquid, such as a light oil, should be placed inside the vacuum to wet the powder to prevent combustion.

7. Skin contact with spent cartridges should be avoided whenever possible to reduce the likelihood of the hand–to–mouth source of lead exposure. Cartridges should be collected together using a floor squeegee and picked up using a dust pan or the HEPA vacuum. All clean–up should be performed with the ventilation system running.

8. Surfaces inside the indoor range should be cleaned routinely with a high-phosphate detergent, such as trisodium phosphate (TSP), to reduce surface lead contamination.

9. Personnel performing clean–up of lead at the trap should wear appropriate respiratory protection (for example, half–face respirators equipped with HEPA filters) and full protective outer clothing (which may be disposable). Personnel performing the clean–up should be included in a respiratory protection program as defined by OSHA in 29 CFR 1910.134. Smoking or eating should be prohibited during clean–up. After clean–up, workers should remove their outer clothing inside the range area to prevent spreading lead to other parts of the building. Non–disposable protective clothing should be laundered by the employer, not taken home.

10. Loose lead in the trap, including spent bullets and lead chiseled from the trap, should be collected with the HEPA vacuum to avoid skin contact with lead. Disposable gloves should be worn to remove larger pieces that cannot be removed with the HEPA vacuum. Care should be taken to prevent over–filling the vacuum to the point that it is difficult to move or empty.

11. Only authorized personnel (range officer and maintenance personnel) should be permitted to go downrange of the firing line. Personnel going downrange should wear protective clothing (disposable or laundered by employer) to cover portions of the body which will be in contact with lead–covered surfaces. Adequate time should be allowed for airborne lead fume and dust in the range to be removed by the ventilation system before personnel are allowed downrange.

12. At the indoor ranges, barricade shooting should only be performed from the shooting booth. To help prevent personnel from going downrange malfunctioning target equipment should be promptly repaired or not used.

13. Carpeting should not be used anywhere inside the range because it becomes a lead dust "reservoir." Unspent primer could also accumulate in the carpeting, creating a potential fire hazard. The carpeting in the indoor ranges should be removed.

14. To maximize efficiency of the ventilation system, back–flow and air distribution problems in the students' range should be corrected as follows:

- ✦ Missing turning vanes in the air wall plenum should be replaced. In addition, debris stuck in the vanes should be removed, and the source of the debris should be eliminated.

- ✦ Materials stored in the air wall plenum should be removed and stored elsewhere. A policy should be instituted forbidding the area to be used for storage. A sign stating that the area is not to be used for storage should be posted on the door to the plenum.

- ✦ Obstructions to the air flow from the air wall should be minimized. Fixtures and equipment which are not needed constantly, and materials stored inside the range, should be removed and stored elsewhere. Vertical surface areas should be minimized. For example, the desk upon which the control console currently sits should be replaced with a table.

- ✦ Obstructions uprange of the booths should be moved as close to the air wall as possible.

15. The desk in the gunsmiths' range should be replaced with a table to eliminate back–flow. In addition, the current tool cabinets next to the desk should be replaced with cabinets on the uprange end of the wall. The new cabinets should be positioned so that they do not interfere with the supply air flow.

16. All leaks from the gunsmiths' range into the students' range should be tightly sealed. Expanding foam insulation can be used to seal the leaks.

17. The plenum that contains the supply air filters and heating coils for the ventilation system should be extended to include the supply fan. This plenum should be made as airtight as possible. In addition, the feasibility of adding cooling coils to cool the supply air should be investigated.

18. The exhaust system should be renovated as follows:

- ✦ A new exhaust air/filter plenum should be installed outside of the building next to the current exhaust fan room. A new plenum is necessary because the current exhaust fan room is too small to accommodate a new plenum with a filtration system. This plenum should be air tight and equipped with pre–filter and HEPA filter systems. These filter systems should be located upstream of the fan. The capacity of the current exhaust fan should be analyzed to verify that the fan can adequately control both ranges. If the fan is inadequate, it should be replaced.

✦ The current exhaust fan room and contents should be decontaminated prior to removal of the exhaust fan.

✦ To prevent settling of lead dust in the ducts the current exhaust ducts should be replaced with ducts sized for a velocity of 3500 feet per minute.[27] Decontamination of the old ducts may be needed before removal. Ducts from the ranges should be connected directly to the plenum.

✦ Protection for the exhaust ducts in the ranges should be improved to prevent additional bullet holes. Holes currently in the ducts should be patched.

✦ The exhaust flow specified in the design for the gunsmiths' range should be changed so that the range is under negative pressure.

19. While the previously discussed recommendations have been aimed at preventing or minimizing lead exposure, medical monitoring plays an important role to ensure that individual workers have been protected. The OSHA lead standard (29 CFR 1910.1025)[20] requires biological monitoring of lead exposed workers every six months for those exposed above the TWA action level of 30 µg/m^3 for more than 30 days per year. In one study, the BLLs of law enforcement trainees using firing ranges for an average of 7.2 hours during their first month of training rose from a mean of 6 µg/dl to 51 µg/dl.[28] Under these conditions, assuming a linear relationship between hours of exposure and BLL, employees using or working at the firing range more than 3.6 hours per month could be at risk for BLLs rising above 40 µg/dl. Assuming the same environmental conditions, these findings suggest that individuals using or working at the range for more than 3 hours per month, should have their BLL monitored. We recommend that FBI instructors, gunsmiths, and range technicians should continue to have their BLLs checked at least annually. Monitoring frequency should be modified on an individual basis depending on worker exposures, previous BLL test results, and any other medical concerns (e.g., pregnancy). FBI trainees should have a baseline BLL at the beginning of training and should then be monitored periodically with frequency dependent upon exposures and BLL results.

20. All employees should be strongly encouraged to use <u>both</u> ear muffs and ear plugs when working on or near the firing ranges. A training program in the use of ear plugs should be implemented by the training staff at the firing ranges. Proper insertion techniques can be easily shown to workers before allowing them to enter the range.

21. All workers with regular exposure to weapons firing should undergo annual audiometric monitoring. All audiometric testing should include the test frequencies of 500, 1000, 2000, 3000, 4000, 6000, and 8000 Hz.

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Table 1

Blood Lead Testing Results, 1989–1991
FBI Academy, Quantico, VA
HETA 91-0346

Group	Year	No. Workers with BLLs Done	Mean BLL (µg/dl) (range)
Instructors (16)	1989	7	14.6 (5–21)
	1990	7	13.7 (6–27)
	1991	14	7.6 (<4–12)
Gunsmiths (13)	1989	5	12.2 (8–15)
	1990	5	11.0 (5–18)
	1991	11	12.1 (<4–24)
Range Techs (6)	1989	5	16.2 (10–24)
	1990	5	10.4 (6–14)
	1991	5	13.6 (8–28)
Custodians (6)	1989	0	–
	1990	0	–
	1991	6	<4.0

BLL = blood lead level
µg/dl = micrograms per deciliter

Table 2

PBZ and Area Airborne Exposure Concentrations for ***Lead***
Outdoor Range: Field 2
FBI Academy, Quantico, Virginia
December 11, 1991
HETA 91–0346

Sample type/location	Time (minutes)	Volume (liters)	Pb Concentration ($\mu g/m^3$)
PBZ - FBI Instructor A	206	412	n.d.
PBZ - FBI Instructor B	191	382	n.d
PBZ - FBI Instructor C	197	394	5.1
PBZ - FBI Instructor D	212	424	n.d
PBZ - FBI Instructor E	260	520	n.d
PBZ - FBI Instructor F	238	476	n.d
area: inside shelter	165	495	n.d
area: on light pole	164	492	n.d

PBZ = personal breathing zone
Pb = lead
µg = micrograms
$\mu g/m^3$ = micrograms per cubic meter
n.d. = none detected

Rounds fired: 1024 (12-gauge shotguns)
3200 (9-mm handguns)

Minimum detectable concentration for a 400-liter sample = 2.5 $\mu g/m^3$
Minimum quantifiable concentration for a 400-liter sample = 8.3 $\mu g/m^3$

Table 3

PBZ and Area Airborne Exposure Concentrations for ***Lead***
Outdoor Range: Field 2
FBI Academy, Quantico, VA
December 12, 1991
HETA 91–0346

Sample type/location	Time (minutes)	Volume (liters)	Pb Concentration ($\mu g/m^3$)
PBZ - FBI Instructor E	171	342	38.0
PBZ - FBI Instructor A	174	348	51.7
PBZ - FBI Instructor C	132	264	15.2
PBZ - FBI Instructor D	170	340	n.d.
PBZ - FBI Instructor F	165	330	15.2
PBZ - FBI Instructor B	165	330	45.5
PBZ - FBI Instructor G	161	322	18.6
area: on light pole	168	420	2.4

PBZ = personal breathing zone
Pb = lead
μg = micrograms
$\mu g/m^3$ = micrograms per cubic meter
n.d. = none detected

Rounds fired: 1024 (12-gauge shotguns)
5760 (9-mm handguns)

Minimum detectable concentration for a 330-liter sample = 3.0 $\mu g/m^3$
Minimum quantifiable concentration for a 330-liter sample = 10 $\mu g/m^3$

Table 4

PBZ and Area Airborne Exposure Concentrations for ***Lead***
Outdoor Range: Field 1
FBI Academy, Quantico, VA
December 12, 1991
HETA 91–0346

Sample type/location	Time (minutes)	Volume (liters)	Pb Concentration ($\mu g/m^3$)
PBZ - FBI Instructor H	184	359	8.4
PBZ - FBI Instructor I	200	400	10.0
PBZ - FBI Instructor J	195	390	5.1
PBZ - FBI Instructor K	188	357	5.6
PBZ - FBI Instructor L	195	390	5.1
PBZ - FBI Instructor M	249	498	n.d.
area: on light pole	201	492	2.0

PBZ = personal breathing zone
Pb = lead
µg = micrograms
$\mu g/m^3$ = micrograms per cubic meter
n.d. = none detected

Weapons fired: 9-mm handguns

Minimum detectable concentration for a 400-liter sample = 2.5 $\mu g/m^3$
Minimum quantifiable concentration for a 400-liter sample = 8.3 $\mu g/m^3$

Table 5

PBZ and Area Airborne Exposure Concentrations for ***Lead***
Outdoor Range: Field 3
FBI Academy, Quantico, VA
December 12, 1991
HETA 91–0346

Sample type/location	Time (minutes)	Volume (liters)	Pb Concentration (µg/m^3)
PBZ - DEA Instructor A	167	334	6.0
PBZ - DEA Instructor B	109	218	9.2
PBZ - DEA Instructor C	115	230	17.4
PBZ - DEA Instructor D	113	226	13.3
area: on light pole	176	440	n.d.

PBZ = personal breathing zone
Pb = lead
µg = micrograms
µg/m^3 = micrograms per cubic meter
n.d. = none detected

Rounds fired: 2200 (9-mm handguns)

Minimum detectable concentration for a 230-liter sample = 4.3 µg/m^3
Minimum quantifiable concentration for a 230-liter sample = 14.3 µg/m^3

Table 6

PBZ and Area Airborne Exposure Concentrations for ***Lead***
Outdoor Ranges: Electric Range and Stress Obstacle Course
FBI Academy, Quantico, VA
December 11, 1991
HETA 91–346

Sample type/location	Time (minutes)	Volume (liters)	Pb Concentration ($\mu g/m^3$)
Samples collected at electric range			
PBZ - FBI Instructor N	263	526	n.d.
PBZ - FBI Instructor I	206	412	4.9
area: behind firing line	249	747	n.d.
Samples collected at stress obstacle course			
PBZ - FBI Instructor O	235	470	29.8
PBZ - FBI Instructor L	232	464	30.2
area: at start of course	243	608	n.d.

PBZ = personal breathing zone
Pb = lead
µg = micrograms
$\mu g/m^3$ = micrograms per cubic meter
n.d. = none detected

Minimum detectable concentration for a 470-liter sample = 2.1 $\mu g/m^3$
Minimum quantifiable concentration for a 470-liter sample = 7.0 $\mu g/m^3$

Table 7
Airborne Exposure Concentrations for ***Lead***
Students' Indoor Range
FBI Academy, Quantico, VA
December 11, 1991
HETA 91–0346

Sample location	Time (minutes)	Volume (liters)	Pb Concentration (µg/m³)
No weapon firing during sampling period			
outside air intake	160	400	n.d.
just inside intake	145	326	n.d.
intake plenum	145	363	n.d.
behind pegboard	152	456	n.d.
control table	136	340	n.d.
station #17	138	345	n.d.
down-range pillar	137	411	n.d.
exhaust fan room	143	358	2.8
outside exhaust	157	353	22.7
Samples collected during shooting session			
outside air intake	94	212	n.d.
just inside intake	100	225	n.d.
intake plenum	98	239	n.d.
behind pegboard	106	318	n.d.
control table	84	189	n.d.
just behind #14	62	186	n.d.
station #14	60	150	n.d.
station #17	87	196	n.d.
down-range pillar	85	255	145.1
exhaust fan room	92	207	338.2
outside exhaust	93	209	186.6

PBZ = personal breathing zone
Pb = lead
µg = micrograms
µg/m³ = micrograms per cubic meter
n.d. = none detected
Minimum detectable concentration for a 250-liter sample = 4.0 µg/m³
Minimum quantifiable concentration for a 250-liter sample = 13.2 µg/m³
Minimum detectable concentration for a 400-liter sample = 2.5 µg/m³
Minimum quantifiable concentration for a 400-liter sample = 8.3 µg/m³

Table 8

PBZ Airborne Concentrations for ***Lead***
Range Technicians
FBI Academy, Quantico, VA
December 11 & 12, 1991
HETA 91–0346

Sample type/location	Time (minutes)	Volume (liters)	Pb Concentration ($\mu g/m^3$)
December 11, 1991			
PBZ - Range Technician A	384	768	n.d.
PBZ - Range Technician B	153	306	n.d.
PBZ - Range Technician C	380	760	2.6
PBZ - Range Technician D	376	752	2.7
PBZ - Range Technician E	458	916	2.2
PBZ - Range Technician F	395	790	n.d.
December 12, 1991			
PBZ - Range Technician D	231	462	n.d.
PBZ - Range Technician A	235	470	n.d.
PBZ - Range Technician E	231	462	n.d.
PBZ - Range Technician F	238	476	n.d.
PBZ - Range Technician C	237	474	n.d.
PBZ - Range Technician B	242	484	n.d.

PBZ = personal breathing zone
μg = micrograms
$\mu g/m^3$ = micrograms per cubic meter
Pb = lead
n.d. = none detected

Minimum detectable concentration for a 750-liter sample = 1.3 $\mu g/m^3$
Minimum quantifiable concentration for a 750-liter sample = 4.4 $\mu g/m^3$

Minimum detectable concentration for a 400-liter sample = 2.1 $\mu g/m^3$
Minimum quantifiable concentration for a 400-liter sample = 7.0 $\mu g/m^3$

Table 9
PBZ and Area Airborne Exposure Concentrations for ***Lead***
Gunsmiths
FBI Academy, Quantico, VA
December 11 & 12, 1991
HETA 91–0346

Sample type/location	Time (minutes)	Volume (liters)	Pb Concentration ($\mu g/m^3$)
December 11, 1991			
PBZ - Gunsmith A	538	1022	2.0
PBZ - Gunsmith B	429	837	n.d.
PBZ - Gunsmith C	444	888	4.5
PBZ - Gunsmith D	495	990	n.d.
PBZ - Gunsmith E	411	801	0.0
PBZ - Gunsmith F	523	1046	3.8
PBZ - Gunsmith G	408	796	n.d.
PBZ - Gunsmith H	445	890	n.d.
PBZ - Gunsmith I	439	878	n.d.
area - firing table	502	1506	4.6
December 12, 1991			
PBZ - Gunsmith A	504	1008	n.d.
PBZ - Gunsmith E	467	934	1.1
PBZ - Gunsmith H	460	920	n.d.
PBZ - Gunsmith C	506	1012	n.d.
PBZ - Gunsmith J	311	606	n.d.
PBZ - Gunsmith B	396	792	n.d.
PBZ - Gunsmith I	421	842	n.d.
PBZ - Gunsmith G	492	984	n.d.
PBZ - Gunsmith F	242	484	n.d.
area - firing table	512	1024	1.0

PBZ = personal breathing zone; Pb = lead
μg = micrograms; $\mu g/m^3$ = micrograms per cubic meter
n.d. = none detected
Minimum detectable concentration for a 900-liter sample = 1.1 $\mu g/m^3$
Minimum quantifiable concentration for a 900-liter sample = 3.7 $\mu g/m^3$

Table 10
PBZ and Area Airborne Exposure Concentrations for ***Lead***
Indoor Range and Linen Room
FBI Academy, Quantico, VA
December 12, 1991
HETA 91–0346

Sample type/location	Time (minutes)	Volume (liters)	Pb Concentration (µg/m³)
PBZ - HRT agent shooting in indoor range	86	172	n.d.
area: linen room adjacent to indoor range	524	1048	n.d.

PBZ = personal breathing zone   Pb = lead
µg = micrograms   µg/m³ = micrograms per cubic meter
n.d. = none detected

Sample collected in indoor range
Rounds fired: 182 (9-mm handgun)

Minimum detectable concentration for a 1048-liter sample = 1.0 µg/m³
Minimum quantifiable concentration for a 1048-liter sample = 3.1 µg/m³

Table 11
PBZ Airborne Exposure Concentrations for ***Lead***
Indoor Range Custodians
FBI Academy, Quantico, VA
December 12, 1991
HETA 91–0346

Sample type/location	Time (minutes)	Volume (liters)	Pb Concentration (µg/m³)
PBZ - Custodian A*	51	102	127.5
PBZ - Custodian B*	50	100	220.0
PBZ - Custodian C**	42	84	n.d.

Samples were collected while workers cleaned the indoor range.
*These workers cleaned the cement floor of the range.
**This worker vacuumed the carpet behind the firing line.
PBZ = personal breathing zone   Pb = lead
µg = micrograms   µg/m³ = micrograms per cubic meter
n.d. = none detected
Minimum detectable concentration for a 100-liter sample = 10 µg/m³
Minimum quantifiable concentration for a 100-liter sample = 33 µg/m³

Table 12

FBI Academy, Quantico, VA
December 11 & 12, 1991
HETA 91–0346

Sample number	Total Sample Concentration (μg/g)	ln Total Sample Concentration (μg/g)	Sample number	Total Sample Concentration (μg/g)	ln Total Sample Concentration (μg/g)
101	169	5.13	201	52	3.94
102	174	5.16	202	188	5.24
103	141	4.95	203	51	3.94
104	393	5.97	204	117	4.76
105	168	5.12	205	53	3.96
106	116	4.75	206	66	4.19
107	352	5.86	207	71	4.26
108	356	5.88	208	51	3.93
109	207	5.33	209	48	3.87
110	546	6.30	210	47	3.84
111	227	5.42	211	58	4.06
112	161	5.08	212	75	4.31
113	179	5.19	213	72	4.28
114	143	4.96	214	50	3.91
geometric mean	214		geometric mean	65	
geometric standard deviation	1.58		geometric standard deviation	1.48	

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