Exposures of Helicopter Pilots and Gunners to Firearm Noise and Lead During Gunnery Target Training Exercises

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Contents

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The cover photo is a close-up image of sorbent tubes, which are used by the HHE Program to measure airborne exposures. This photo is an artistic representation that may not be related to this Health Hazard Evaluation. Photo by NIOSH.

Highlights of this Evaluation

The Health Hazard Evaluation Program received a technical assistance request from a federal agency in Florida. The requestors were concerned about exposures to noise and lead among pilots and gunners during gunnery target training that included shooting high caliber firearms from helicopters.

What We Did

- We evaluated noise and lead exposures in March and April 2010.
- We measured pilots' and gunners' exposures to noise from shooting weapons and from helicopter flights during gunnery target training.
- We measured pilots' and gunners' exposure to lead from shooting ammunition that contained lead.
- We took surface wipe samples for lead inside helicopter cabins.
- We spoke with pilots and gunners about the health symptoms they had while training and during actual missions.

What We Found

- Helicopter pilots and gunners were exposed to high noise levels during gunnery target training.
- Peak noise levels during weapons shooting were high enough to damage hearing.
- Helicopter pilots reported headache and fatigue from gun blast, especially after flights for gunnery target training.
- Gunners did not report health problems from gun blast.
- Employee exposure to lead did not exceed occupational exposure limits.
- We found lead on surfaces inside the helicopter cabin.

We measured federal agency pilots' and gunners' exposures to noise and lead during gunnery target training exercises. Noise exposures from helicopters and gunfire were above National Institute for Occupational Safety and Health exposure limits. Airborne lead exposures were below occupational exposure limits, but surface lead was found inside helicopter cabins. We recommended engineering modifications to the helicopters to reduce noise and blast overpressure exposures.

What the Employer Can Do

- Install a partial noise barrier in the helicopters between the pilots and gunner.
- Install a window on the left side of the helicopter cabin that can be opened to reduce blast pressure when high caliber weapons are shot.
- Continue to require double hearing protection for everyone in the helicopter cabin when they shoot weapons and during gunnery target training flights.
- Test employee hearing using National Institute for Occupational Safety and Health and Occupational Safety and Health Administration criteria.

What Employees Can Do

- Report health symptoms from gunnery target training exercises to medical staff.
- Wear double hearing protection during gunnery target training.
- Wash your hands after shooting firearms and before eating, drinking, or using tobacco products.

Abbreviations

µg/dL	Micrograms per deciliter
µg/100 cm^2	Micrograms per 100 square centimeters
µg/m^3	Micrograms per cubic meter
ACGIH®	American Conference of Governmental Industrial Hygienists
AL	Action level
ANSI	American National Standards Institute
BLL	Blood lead level
CFR	Code of Federal Regulations
dB	Decibels, unweighted
dBA	Decibels, A-weighted
Hz	Hertz
NIHL	Noise-induced hearing loss
NIOSH	National Institute for Occupational Safety and Health
NRR	Noise reduction rating
OEL	Occupational exposure limit
OSHA	Occupational Safety and Health Administration
PEL	Permissible exposure limit
REL	Recommended exposure limit
TLV®	Threshold limit value
TWA	Time-weighted average
WEEL	Workplace environmental exposure level

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Introduction

The Health Hazard Evaluation (HHE) Program received a technical assistance request from managers in the flight safety office of a federal agency concerning helicopter crews' exposures to gunshot noise, vibration, and lead during airborne offshore and ground range gunnery training exercises in Florida. These crews were part of a helicopter interdiction unit that assisted companion sea-based units in the interception and disabling of drug- and contraband-running watercraft. The interdiction unit had 50 pilots and 25 gunners.

Helicopter gunners attempted to disable boat engines through pinpoint rifle fire as the helicopter hovered over a sea vessel. The interdiction unit flew MH-65C "Dolphin" helicopters. During interdiction missions, the gunner sat on the right side of the helicopter and fired a machine gun or sniper rifle out of an open right side aft helicopter door. The left side helicopter door remained closed during missions. Gunners initially used M240 machine guns to fire warning shots across the bow of the vessel. If warning shots did not stop the suspects, gunners used a military long range M107 sniper rifle to disable the vessel by shooting out the engines. The M107 rifle was fitted with a muzzle brake that directed some of the blast overpressure bilaterally backwards at a 45 degree angle. The ammunition contained lead. Interdiction unit gunners conducted yearly gunnery target training exercises to practice shooting weapons.

During an initial site visit early in March 2010, we met with flight safety representatives, pilots, and gunners to discuss the health hazard evaluation request. We also observed work practices and workplace conditions, interviewed four members of the interdiction unit about workplace health and safety concerns, measured whole-body vibration during an offshore gunnery target training exercise, and took surface lead samples from inside two helicopters.

We returned to the interdiction unit's helicopter base in late March through early April 2010 to collect personal air samples for lead and to measure noise during offshore and ground range gunnery target training exercises. We took additional surface lead samples on helicopters, and repeated whole-body vibration measurements. During the offshore gunnery target training exercise, a gunner shot 20 rounds from an M107 .50 caliber (12.7 mm) semiautomatic sniper rifle, 20 rounds from an M240 .308 caliber (7.62 mm) machine gun, and 40 rounds from an M14 .308 caliber (7.62 mm) tactical rifle. During the ground-based gunnery target training exercise, each of five gunners shot 10 rounds from the M107 rifle and 20 rounds from the M240 machine gun.

Methods

Noise

We collected time-weighted average (TWA) personal noise exposure measurements over 2 days on pilots, copilots, and gunners during an offshore training exercise and during ground range gunnery target training exercises. We used Larson Davis Spark™ model 706RC integrating noise dosimeters for personal noise exposure measurements. The dosimeters simultaneously collected data using three different settings to allow comparison of noise measurement results with the three different noise exposure limits referenced in this report, the Occupational Safety and Health Administration (OSHA) permissible exposure limit (PEL), OSHA action level (AL), and the National Institute for Occupational Safety and Health (NIOSH) recommended exposure limit (REL). Personnel only wore noise dosimeters for the duration of the training exercises, including the flight to and return flight from training exercise locations.

We also measured overall noise levels and the noise levels at different frequencies (octave band frequency spectrum analysis) in the cabin of the helicopter using a Larson Davis System 824 sound level meter and real-time frequency analyzer. The preamplifier and microphone were mounted on the back of the seat behind the copilot, with the microphone positioned above the seatback to measure noise within 1.5 feet of the copilot's right ear. The sound level meter was equipped with a 0.25-inch random incidence Type 1 electret microphone.

We obtained audiometric test records for 35 pilots and 26 gunners who worked at the facility at the time of the evaluation. The records contained baseline and most recent audiograms. We analyzed these records to identify potential hearing threshold shift using OSHA and NIOSH criteria.

Lead

We collected 40 surface wipe samples during the two site visits from surfaces inside and outside the helicopter. We focused on collecting samples from surfaces the pilots or gunners would likely touch without gloves. We collected and analyzed surface wipe samples using NIOSH Method 9102 [NIOSH 2013]. For flat surfaces, we used a square template to outline a 100 square centimeter surface area. For irregular or uneven surfaces we estimated the sample area or sampled the entire surface (e.g., seat nob, chin strap, gloves).

We collected seven personal air samples over 2 days for lead on pilots, copilots, and gunners during the offshore gunnery target training exercise and during ground range gunnery target training exercises. We collected and analyzed air samples using NIOSH Method 7303 [NIOSH 2013].

Vibration

We measured whole body vibration on pilots using Quest VI-400Pro real-time vibration monitoring systems. However, the whole body vibration data recorded on the instrument during the evaluation was lost. During our interviews with pilots we learned that they were mostly concerned about muzzle blast overpressure from firing the M107 sniper rifles, but "vibration" was used as a general term for the blast overpressure. The vibration monitors do not suitably measure blast overpressure.

Employee Interviews

In our first site visit we interviewed a convenience sample of three pilots and one gunner in private about workplace health and safety concerns, including any symptoms they related to work.

Results and Discussion

Noise

Measurements taken with the sound level meter in the helicopter cabin showed that peak impulse noise levels during gunfire exceeded 150 decibels (dB). However, the sound level meter was not able to accurately measure noise levels above 150 dB because of instrument limitations, so actual peak noise levels were likely higher. Research has shown that peak noise levels during gunfire often exceed 160 dB [NIOSH 2003, 2005, 2011]. Repeated exposure to impulse noise can result in permanent noise-induced hearing loss (NIHL) [Patterson and Hamernik 1992; Pekkarinen et al. 1993; Chan et al. 2001]. Impulse noise, such as that from gunfire, has sufficient intensity to permanently damage unprotected ears in minutes rather than the days or years typical of industrial noise exposure. The OSHA PEL and NIOSH REL state that exposure to impulse noise should not exceed 140 dB. However, peak impulse is not the sole factor in hearing damage. Other factors such as duration of the impulse and frequency of exposure can also affect hearing loss.

Results from personal noise dosimetry measurements are provided in Table 1. The offshore training exercise lasted for approximately 2 hours 20 minutes, including the time of flight to and from the offshore gunnery target area. Using NIOSH noise monitoring criteria, the pilot's and copilot's TWA noise exposures during the exercise were about 102 decibels, A-weighted (dBA), and the gunner's TWA noise exposure was more than 108 dBA. Using OSHA criteria, the gunner's noise exposure was greater than 100 dBA, and the pilot's and copilot's noise exposures were nearly 100 dBA. Because of the magnitude of the pilots' and gunner's noise exposures during the offshore training exercise, their 8-hour TWA noise exposures were above occupational exposure limits (OELs), even though they had no additional high noise exposure for the rest of their work day.

Figure 1 shows the gunner's noise exposure time history profile during the offshore gunnery target training exercise. Noise exposure levels were at or above 100 dBA during the helicopter flight and were greater than 125 dBA during the live-fire exercise. All the firearms generate high noise levels during shooting. However, noise produced by the .50 caliber M107 was higher than the noise from the lower caliber M14 and M240 weapons.

For ground range training exercises, the pilot and copilot flew several different gunners, one at a time, on short duration land-based gunnery target training exercises. The exercise for each gunner took 15 to 25 minutes. The pilot and copilot were exposed to gunfire and nearly 3 hours of helicopter noise. TWA noise exposures for all personnel engaged in the training exercise were greater than 100 dBA, using NIOSH and OSHA measurement criteria. Even if pilots and gunners had no additional noise exposure for the remainder of their work day, their 8-hour full-shift TWA noise exposures would still exceed the NIOSH REL. The pilots' 8-hour TWA noise exposures would also exceed the OSHA AL and PEL.

Previous research on the use of noise dosimeters for gunfire measurements has shown that the instruments underestimate TWA noise exposures from high intensity impulse noise [Kardous et al. 2003; Kardous and Willson 2004]. Therefore, personal TWA noise measurements from gunfire noise collected with dosimeters should be interpreted cautiously and considered to underrepresent noise exposure and hearing loss risk from gunfire noise.

Table 1. Summary of personal noise exposure measurements

Date	Job title	Sample time (minutes)	TWA for sample period (dBA)			8-hour TWA (dBA)*		
			REL	AL	PEL	REL	AL	PEL
3/31/2010	Pilot	144	101.8	98.8	98.8	96.6	90.2	90.2
3/31/2010	Copilot	143	101.8	99.7	99.7	96.5	91.0	91.0
3/31/2010	Gunner	141	108.5	106.3	106.3	103.2	97.5	97.5
4/1/2010	Pilot	166	104.0	100.3	100.3	99.4	92.7	92.6
4/1/2010	Copilot	169	103.7	101.2	101.2	99.2	93.7	93.7
4/1/2010	Gunner	15	107.7	103.8	103.8	92.8	78.9	78.9
4/1/2010	Gunner	20	107.6	104.4	104.4	93.7	81.4	81.3
4/1/2010	Gunner	22	107.3	104.5	104.5	94.0	82.4	82.3
4/1/2010	Gunner	23	104.3	100.4	100.3	91.0	78.3	78.2

*Assumes personnel have no additional noise exposure during the unsampled period of their work shift

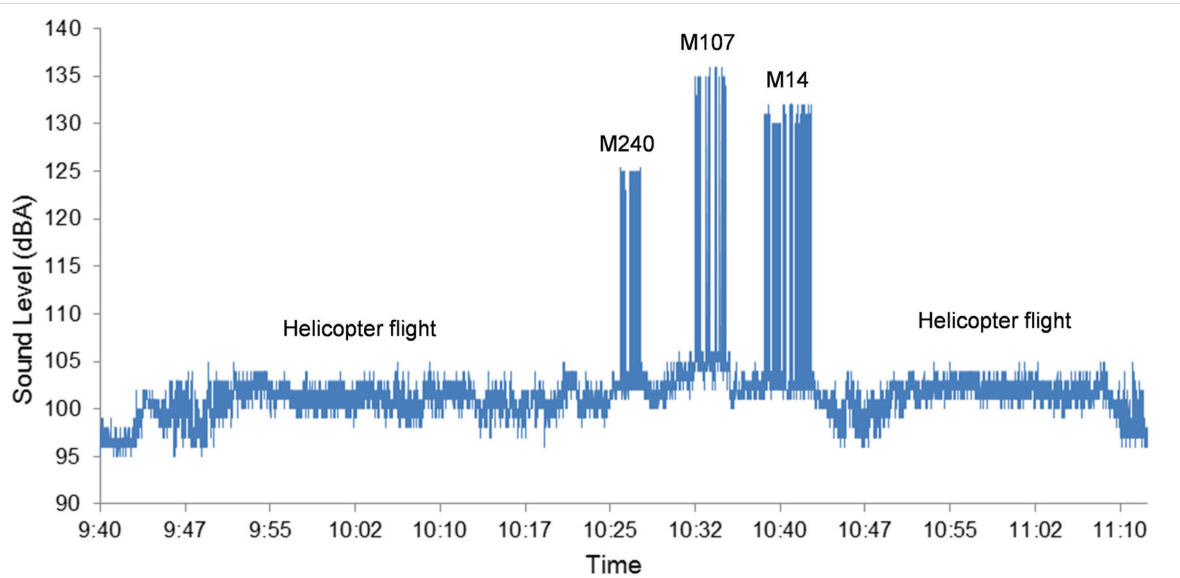


Figure 1. Time history profile for gunner noise exposure during offshore gunnery target training.

Personal noise measurements during helicopter flights (excluding exposure during gunfire) are provided in Table 2. Even though the pilot sat on the right side of the helicopter, closer to the open right rear door, on both days of noise monitoring the pilot's noise exposure was about 2 dBA lower than the copilot's. This was most likely because the pilot's side door blocked some of the noise from the engine and rotors. In contrast, the copilot on the left side seat received little noise reduction from the pilot side door and had a more direct path for noise exposure from the open right rear door.

The gunner's noise exposure from helicopter noise was 7 dBA higher than the pilot's, because the gunner sat next to the open right side rear door and had more direct exposure to engine and rotor noise. These results show that depending on seating location within the helicopter cabin, the occupants' noise exposures would exceed the OSHA PEL in approximately 60 to 160 minutes and would exceed the NIOSH REL in 6 to 25 minutes.

Table 2. Personal noise exposure measurements in the MH65C "Dolphin" cabin during flight

Date	Job title	Sample time (minutes)	TWA for sample period (dBA)		
			REL	AL	PEL
3/31/2010	Pilot	92	97.9	97.8	97.8
3/31/2010	Copilot	92	99.7	99.5	99.5
3/31/2010	Gunner	91	104.6	104.5	104.5
4/1/2010	Pilot	70	98.9	98.8	98.8
4/1/2010	Copilot	68	101.2	100.9	100.9

Previous research on military helicopter aviators has shown hearing loss to be a function of noise exposure from helicopters as measured by total flight hours [Fitzpatrick 1988]. In contrast, Owen [1996] found hearing loss to be correlated with number of years of flying and age of helicopter aviators, but did not find correlation with total flight hours. Additionally, comparison of hearing thresholds in aviators to standardized data for normal males from the International Standards Organization 1999 standards for estimating noise-induced hearing impairment revealed that hearing loss in aviators at 6,000 hertz (Hz) was greater than that due to age alone [Owen 1996]. In addition to exposure to helicopter noise, risk of hearing loss for members of the federal agency interdiction unit includes exposure to high impulse noise from gunfire.

Our review of audiograms revealed that none of the pilots and gunners had a standard threshold shift on the basis of OSHA criteria (Table 3). In contrast, approximately 20% of the pilots and gunners had evidence of a threshold shift on the basis of NIOSH criteria. However, these threshold shifts had not been verified with confirmatory audiometric tests, so some of these shifts may not be persistent and therefore not true threshold shifts. Appendix A explains the difference between the OSHA and NIOSH threshold shift criteria.

Table 3. Number of threshold shifts among pilots and gunners using NIOSH and OSHA threshold shift criteria

	NIOSH threshold shift	OSHA standard threshold shift	No threshold shift	Total audio-metric records
Pilots	7	0	28	35
Gunners	5	0	21	26

Because shooting firearms produces high impulse noise levels and TWA noise exposures were above 100 dBA, double hearing protection is necessary to protect hearing. Research has shown that double hearing protection can provide the additional noise reduction needed in high noise level environments [Berger 1983]. However, proper insertion of hearing protection is critically important to ensure proper noise attenuation. NIOSH has previously identified that poor insertion of formable hearing protection into the ear canals reduces the ability of the hearing protectors to attenuate noise exposure [NIOSH 2005].

Pilot and gunners wore Gentex model HGU-56/P aircrew integrated helmet systems that were equipped with standard earcups for noise attenuation. Previous measurements of real-ear attenuation using American National Standards Institute (ANSI) standard S12.6-1997 Method A experimenter-supervised fit indicated that the noise reduction rating (NRR) for the standard configuration of these helmets ranged from 19.0 dB [AFRL/HECB 2006] to 19.5 dB [USAARL 2005]. Researchers reported that this was similar to the NRR reported by the manufacturer [USAARL 2005]. Additionally, the pilots and gunners wore insert hearing protectors such as Communication and Ear Protection insert earplugs with a manufacturer's labeled NRR of 23 dB or 3M model 1100 foam earplugs with a manufacturer's labeled NRR of 29 dB.

To estimate hearing protector attenuation NIOSH recommends using subject fit data based on ANSI standard S12.6-1997 [ANSI 1997]. If subject fit data are not available, NIOSH recommends derating the hearing protectors' NRR by subtracting 25% from the manufacturer's labeled NRR for earmuffs and subtracting 50% from the manufacturer's labeled NRR for formable earplugs. An additional 5 to 10 dB of attenuation can be added for use of dual hearing protection [NIOSH 1998]. NIOSH has found from testing of hearing protection using an acoustic mannequin that double hearing protection may actually provide more peak noise attenuation than the NIOSH hearing protector derating formula calculates [NIOSH 2003, 2005]. On the basis of hearing protector subject fit test data and attenuation estimates, the combination of earmuffs and insert earplugs used by the pilots and gunners should attenuate impulse noise exposure up to 170 dB, if properly fit and worn. Actual attenuation and fit of hearing protection can be determined through individual hearing protector fit testing [Hager 2011]. Several methods are available using systems developed by hearing protector manufacturers, and research on fit testing of hearing protection is ongoing.

The user's manual for the M107 warns of possible exposure to noise and blast overpressure and requires the use of hearing protection for this firearm [Department of the Army 2004]. The manual also warns of possible injury from "blow by of hot, expanding gases from the muzzle brake." The manual does not make specific recommendations for use from a helicopter. An errata sheet to the manual specifies that the number of rounds fired per 24-hour period should be limited to 24 rounds if single hearing protection is worn and 100 rounds if double hearing protection is worn. It also emphasizes that personnel be aware that the blast from the muzzle brake will blow back during firing at 45 degree angles.

The U.S. Department of Defense specifies the allowable number of rounds from firing weapons in MIL-STD-1474D [DOD 1997]. Alternatively, NIOSH proposed a simplified, conservative formula to reduce the risk of exposure to impulse noise in terms of the number of gunshots to which a person can be exposed per day [NIOSH 2002]:

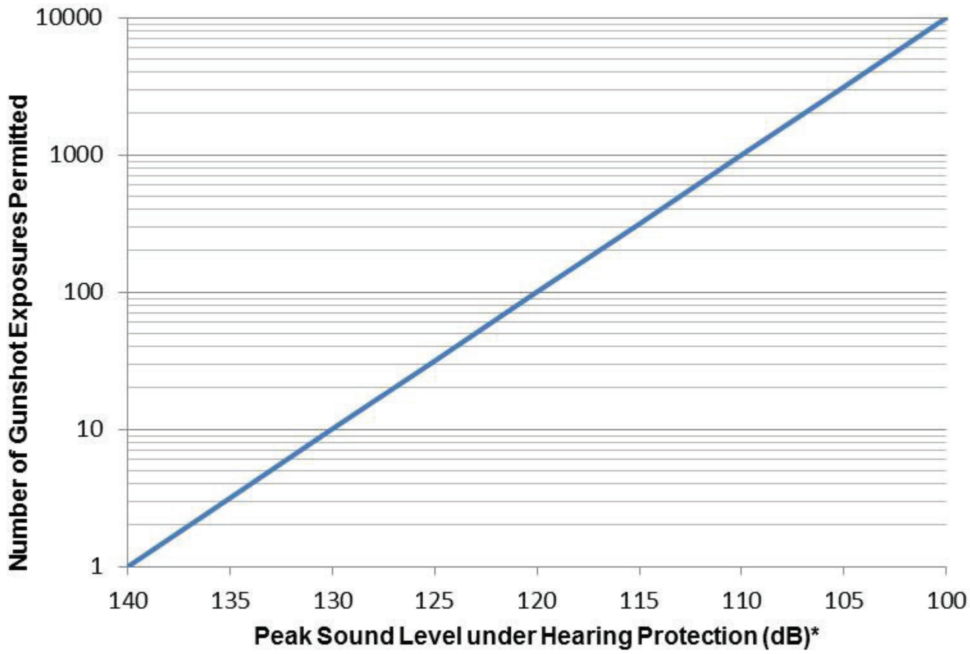
$$N = 10^{((140 - PI)/10)}$$

where N is the number of gunshot exposures permitted, and PI is the peak impulse level in dB under hearing protection. PI is determined by subtracting the noise attenuation for hearing protection from the peak noise exposure level for a gunfire impulse. The NIOSH-proposed formula is a conservative estimate and does not take into account the duration of the impulse, its spectral content, or its energy.

Figure 2 shows the number of gunshot exposures permitted on the basis of peak noise levels under hearing protection. During the HHE gunners and pilots were exposed to 80 rounds of gunfire during the offshore target training exercise and 30 rounds of gunfire during the ground range target training exercises. However, the number of rounds fired per day can vary by type of training exercise performed. The federal agency's Flight Safety Office limits the number of rounds to 100 per day. The NIOSH formula permits 100 rounds of gunfire exposure if hearing protection attenuates peak levels under hearing protection to 120 dB. Assuming peak noise levels during gunfire range from 160 to 170 dB [NIOSH 2003, 2005, 2011], hearing protection would need to attenuate peak noise levels by 40 to 50 dB to allow 100 rounds of gunfire exposure. The federal agency can best determine the noise attenuation of hearing protection used by gunners and pilots by having hearing protector fit testing completed.

Blast Overpressure

The main concern reported by the three pilots we interviewed was repeated exposure to muzzle blast overpressure from the M107 sniper rifle used by gunners. The configuration of the M107's muzzle brake deflects part of the blast outward toward the sides and back. The pilot seated on the right side of the helicopter sits in the path of the muzzle blast deflection. The pilots reported that the most frequent and prolonged exposure to blast overpressure occurred during weapons training and qualification exercises. Per the U.S. Army manual, which the flight safety office used as a guideline, aircrew can be exposed to close to the maximum limit of 100 shots from the M107 within 24 hours. Pilots described the feeling of this overpressure as "being hit on the face with a pillow." Pilots reported feeling fatigue and headaches from exposure to repeated blast overpressure



*Peak sound level under hearing protection is calculated by subtracting the estimated noise attenuation for hearing protection from the peak noise exposure level for a gunfire impulse.

Figure 2. Number of gunshot exposures permitted using NIOSH recommendations [NIOSH 2002], on the basis of peak sound levels (dB) under hearing protection.

from weapons fire, particularly after weapons training and practice sessions at the gunnery range. The fatigue and headaches resolved with rest. Pilots said that not knowing when the shots would come—the repeated surprises of the blast overpressure—made it especially straining. None of the pilots interviewed reported any persistent health effects from the blast overpressure. The gunner we interviewed stated he was not affected by the blast overpressure while shooting the M107 because he was positioned behind the gun and out of the path of the muzzle blast deflection.

In September 2007, Global Helicopter Technologies, a contractor, conducted ground-based static weapons firing tests of several different firearms, including the M107, in an HH-65 helicopter, which is similar to the MH-65 helicopter. The purpose of the testing was to evaluate the susceptibility of the airframe and windows to blast overpressure during weapons fire. The highest measured blast pressure from shooting a M107 sniper rifle in the starboard aft direction from the helicopter was 25 to 26 PSI on the airframe at a distance of 6.1 inches from the muzzle of the weapon [Global Helicopter Technology 2008]. Tests showed that the combination of muzzle blast pressure and position of the weapon muzzle relative to the windows during firing resulted in damage such as blowing out or cracking the starboard sliding door windows of the helicopter.

Peak pressure decreases with increasing distance. We were not able to accurately measure peak blast overpressure levels near the gunner, pilot, or copilot after firing the M107 sniper rifle because of electronic limitations of the sound level meter. However, peak pressures inside the cabin should be substantially less than those measured near the muzzle because the pressure wave is reduced with increasing distance from the muzzle and partial disruption of the pressure wave by the exterior of the helicopter body and seats or other objects inside the cabin.

In response to the Global Helicopter Technologies report, the federal agency modified the location of the firearm barrel attachment ring on the fore and aft of the door opening. With this change, the gunner was able to extend the M107 muzzle further away from the helicopter cabin during shooting, which should have reduced blast overpressure on the helicopter and its occupants. The increased distance would have also likely reduced noise exposures of the cabin crew and gunners. The federal agency also began to use different muzzle brakes that changed the angle and pattern of blast dispersion after firing the M107. Reduction of air crew exposures to blast pressure and impulse noise levels may also be reduced by installing a partial barrier, such as a fitted acrylic glass or noise-dampening bulkhead, between the gunner and the aircrew. However, this would not reduce gunners' exposures. Installation of a small window opening on the left side of the helicopter could also lower internal cabin pressure during gunfire.

Lead

Personal air sampling results for lead are presented in Table 4. The lead concentrations ranged from nondetectable to 26 micrograms per cubic meter (µg/m^3) over the duration of the training sessions (20–146 minutes). Assuming that the pilots and gunners received no further exposure to airborne lead during their work shift, these results equate to 8-hour TWAs for lead ranging from 0.30 to 7.8 µg/m^3. These exposures are well below the NIOSH REL, OSHA PEL, and OSHA AL for airborne lead exposure. The pilot, seated on the right side of the helicopter, had slightly higher exposures to airborne lead than the copilot, seated on the left. This could be because of the pilot's closer proximity to the muzzle blast. However, because of the limited number of samples collected, these differences in exposure levels could be due to random error. Additional samples would need to be collected to determine if the two pilots have statistical differences in exposure.

Table 4. Personal breathing zone air sample results for lead on pilots and gunners

Date	Job title	Sample time (minutes)	Sampling period lead concentration (µg/m^3)	8-hour TWA lead concentration (µg/m^3)
03/31/2010	Pilot	141	(2.4)	0.70
	Copilot	134	ND*	—
	Gunner	136	(1.1)	0.30
04/01/2010	Pilot	144	26	7.8
	Copilot	146	2.8	0.90
	Gunner 1	21	ND†	—
	Gunner 2	20	ND†	—
	Gunner 3	22	(6.6)	0.30
	Gunner 4	22	ND†	—
NIOSH recommended exposure limit				50
OSHA action level				30
OSHA permissible exposure limit				50

*ND = not detected; below the minimum detectable concentration of 0.71 µg/m^3 for an average sample time of 140 minutes.

†ND = not detected; below the minimum detectable concentration of 4.7 µg/m^3 for an average sample time of 21 minutes.

( ) = Concentrations between the minimal detectable and minimal quantifiable concentrations are shown in parentheses to acknowledge that there is more uncertainty surrounding concentrations below the MQC.

We collected wipe samples for lead from interior surfaces of the helicopter cabins. Results are presented in Table 5. Lead levels ranged from 0.42 to 11 micrograms per 100 square centimeters (µg/100 cm^2) on surfaces that the gunners might touch, and 0.11 to 9.0 µg/100 cm^2 on surfaces that the pilots might touch. Generally, there is little or no correlation between surface lead levels in the workplace and employee exposures, because ingestion exposures are highly dependent on personal hygiene practices and available facilities for maintaining personal hygiene. However, lead-contaminated surfaces are a potential source of exposure for pilots and gunners, particularly if they touch these surfaces without gloves.

Neither NIOSH nor OSHA has established surface contamination limits for lead in the workplace. The U.S. EPA and HUD limit lead on surfaces in public buildings and child-occupied housing to less than 40 micrograms of lead per square foot [EPA 1998; HUD 2012]. The OSHA lead standard requires that all surfaces be maintained "as free as practicable of accumulations of lead" [29 CFR 1910.1025(h)(1)].

The federal agency did not clean the inside of the helicopters to remove lead, and cloth seats were replaced only if damaged or excessively worn. The presence of surface lead inside the helicopters shows that some contamination has occurred and suggests that improved cleaning of these surfaces is advisable. Periodic cleaning, such as quarterly, inside helicopters could help reduce lead accumulation even further, help prevent contamination of skin and clothes, and decrease the opportunity for accidental ingestion. General all-purpose cleaners have been shown to be adequate for removing lead-contaminated dust from surfaces [EPA 1997], and no special disposal is required for cleaning cloths and materials. Vacuums equipped with high efficiency particulate air filters can also be used for cleaning. Air crew and gunners should also maintain good hand hygiene and thoroughly wash their hands after handling guns or bullets that contain lead, and after gunnery target training exercises. If soap and water are not immediately available, lead removal wipes can also be used to clean hands.

Table 5. Surface wipe sample results for lead

Sampling locations	Lead levels (µg/100 cm^2)*
Gunners	
Ammo case	2.2–0.65
Gun mount	3.5–11
Gunner screen	0.91–5.1
Gunner seat knob	0.54–1.3
Gunner chin strap	0.42
Gunner gloves	4.8
Pilots	
Left door handle	(0.35)–2.4
Left fabric handle	(0.11)–(0.43)
Right door handle	0.80–9.0
Right fabric handle	(0.52)–(1.0)
Right pilot yoke	0.51–0.84

*For irregular or uneven surfaces we estimated the sample area or sampled the entire surface (e.g., seat nob, chin strap, gloves).

( ) = Concentrations between the minimal detectable and minimal quantifiable concentrations are shown in parentheses to acknowledge that there is more uncertainty surrounding concentrations below the MQC.

Conclusions

Air crews and gunners were exposed to excessive noise from gunfire and noise from the helicopter engine and rotors during interdiction gunnery training exercises. Gunfire was the primary contributor to noise exposure with peak levels exceeding 150 dB and TWA exposures above 100 dBA during the exercises. Audiometric test results showed that some of the pilots and gunners had evidence of threshold shifts using NIOSH criteria, but did not have standard threshold shift using OSHA criteria. Personal measurements for airborne lead did not exceed OELs, but lead dust was found on surfaces in the helicopter cabins.

Recommendations

On the basis of our findings, we recommend the actions listed below. We encourage the helicopter interdiction unit to use a labor-management health and safety committee or working group to discuss our recommendations and develop an action plan. Those involved in the work can best set priorities and assess the feasibility of our recommendations for the specific situation at the helicopter interdiction unit.

Our recommendations are based on an approach known as the hierarchy of controls (Appendix A). This approach groups actions by their likely effectiveness in reducing or removing hazards. In most cases, the preferred approach is to eliminate hazardous materials or processes and install engineering controls to reduce exposure or shield employees. Until such controls are in place, or if they are not effective or feasible, administrative measures and personal protective equipment may be needed.

Elimination and Substitution

Eliminating or substituting hazardous processes or materials reduces hazards and protects employees more effectively than other approaches. Prevention through design, considering elimination or substitution when designing or developing a project, reduces the need for additional controls in the future.

1. Consider using non-lead bullets and non-lead primers as they become economically feasible.

Engineering Controls

Engineering controls reduce employees' exposures by removing the hazard from the process or by placing a barrier between the hazard and the employee. Engineering controls protect employees effectively without placing primary responsibility of implementation on the employee.

1. Continue to try alternative muzzle brakes to reduce blowback of blast pressure during firing of .50 caliber weapons.
2. Install a fitted partial acrylic or noise-dampening bulkhead behind the pilot seats in the helicopters to reduce peak noise and blast overpressure exposures.
3. Install a small window on the left side of the helicopter cabin that can be opened during gunfire from .50 caliber weapons. This action will help dissipate internal cabin pressure

Administrative Controls

The term administrative controls refers to employer-dictated work practices and policies to reduce or prevent hazardous exposures. Their effectiveness depends on employer commitment and employee acceptance. Regular monitoring and reinforcement are necessary to ensure that policies and procedures are followed consistently.

1. Continue to provide annual audiometric evaluations. To improve detection of potential hearing loss, use NIOSH criteria in addition to OSHA criteria to identify hearing threshold shifts and include the 8,000 Hz frequency in audiometric tests. Reviewers of audiograms should consider the effects of ototoxins, such as lead, on hearing loss.
2. Clean the inside of the helicopter cabins on a quarterly basis to help remove surface lead accumulation. General all-purpose cleaners and vacuums equipped with high efficiency particulate air filters and can be used to remove lead-contaminated dust from surfaces. No special disposal is required for cleaning cloths and materials.
3. Advise air crew and gunners to maintain good hand hygiene and thoroughly wash their hands after handling guns or bullets that contain lead and after gunnery target training exercises. If soap and water are not immediately available, air crews and gunners should use lead removal wipes to clean their hands.
4. Follow the medical surveillance guidelines outlined in Appendix A for pilots and gunners exposed to lead.

Personal Protective Equipment

Personal protective equipment is the least effective means for controlling hazardous exposures. Proper use of personal protective equipment requires a comprehensive program and a high level of employee involvement and commitment. The right personal protective equipment must be chosen for each hazard. Supporting programs such as training, change-out schedules, and medical assessment may be needed. Personal protective equipment should not be the sole method for controlling hazardous exposures. Rather, personal protective equipment should be used until effective engineering and administrative controls are in place.

1. Ensure that flight crew and gunners are fitted for and continue to use double hearing protection. For maximum protection, provide ear plugs that have a high level of noise attenuation.

Appendix A: Occupational Exposure Limits and Health Effects

NIOSH investigators refer to mandatory (legally enforceable) and recommended OELs for chemical, physical, and biological agents when evaluating workplace hazards. OELs have been developed by federal agencies and safety and health organizations to prevent adverse health effects from workplace exposures. Generally, OELs suggest levels of exposure that most employees may be exposed to for up to 10 hours per day, 40 hours per week, for a working lifetime, without experiencing adverse health effects. However, not all employees will be protected if their exposures are maintained below these levels. Some may have adverse health effects because of individual susceptibility, a pre-existing medical condition, or a hypersensitivity (allergy). In addition, some hazardous substances act in combination with other exposures, with the general environment, or with medications or personal habits of the employee to produce adverse health effects. Most OELs address airborne exposures, but some substances can be absorbed directly through the skin and mucous membranes.

Most OELs are expressed as a TWA exposure. A TWA refers to the average exposure during a normal 8- to 10-hour workday. Some chemical substances and physical agents have recommended short-term exposure limit or ceiling values. Unless otherwise noted, the short-term exposure limit is a 15-minute TWA exposure. It should not be exceeded at any time during a workday. The ceiling limit should not be exceeded at any time.

In the United States, OELs have been established by federal agencies, professional organizations, state and local governments, and other entities. Some OELs are legally enforceable limits; others are recommendations.

- The U.S. Department of Labor OSHA PELs (29 CFR 1910 [general industry]; 29 CFR 1926 [construction industry]; and 29 CFR 1917 [maritime industry]) are legal limits. These limits are enforceable in workplaces covered under the Occupational Safety and Health Act of 1970.

- NIOSH RELs are recommendations based on a critical review of the scientific and technical information and the adequacy of methods to identify and control the hazard. NIOSH RELs are published in the NIOSH Pocket Guide to Chemical Hazards [NIOSH 2010]. NIOSH also recommends risk management practices (e.g., engineering controls, safe work practices, employee education/training, personal protective equipment, and exposure and medical monitoring) to minimize the risk of exposure and adverse health effects.

- Other OELs commonly used and cited in the United States include the threshold limit values (TLVs), which are recommended by the American Conference of Governmental Industrial Hygienists (ACGIH), a professional organization, and the workplace environmental exposure levels (WEELs), which are recommended by the American Industrial Hygiene Association, another professional organization. The TLVs and workplace environmental exposure levels are developed by committee members of these associations from a review of the published, peer-reviewed literature. These OELs are not consensus standards. TLVs are considered voluntary exposure guidelines for use by industrial hygienists and others trained in this discipline "to assist in the control of health hazards" [ACGIH 2013]. Workplace environmental exposure levels have been established for some chemicals "when no other legal or authoritative limits exist" [AIHA 2013].

Outside the United States, OELs have been established by various agencies and organizations and include legal and recommended limits. The Institut für Arbeitsschutz der Deutschen Gesetzlichen Unfallversicherung (Institute for Occupational Safety and Health of the German Social Accident Insurance) maintains a database of international OELs from European Union member states, Canada (Québec), Japan, Switzerland, and the United States. The database, available at http://www.dguv.de/ifa/Gefahrstoffdatenbanken/GESTIS-Internationale-Grenzwerte-für-chemische-Substanzen-limit-values-for-chemical-agents/index-2.jsp, contains international limits for more than 1,500 hazardous substances and is updated periodically.

OSHA requires an employer to furnish employees a place of employment free from recognized hazards that cause or are likely to cause death or serious physical harm [Occupational Safety and Health Act of 1970 (Public Law 91–596, sec. 5(a)(1))]. This is true in the absence of a specific OEL. It also is important to keep in mind that OELs may not reflect current health-based information.

When multiple OELs exist for a substance or agent, NIOSH investigators generally encourage employers to use the lowest OEL when making risk assessment and risk management decisions. NIOSH investigators also encourage use of the hierarchy of controls approach to eliminate or minimize workplace hazards. This includes, in order of preference, the use of (1) substitution or elimination of the hazardous agent, (2) engineering controls (e.g., local exhaust ventilation, process enclosure, dilution ventilation), (3) administrative controls (e.g., limiting time of exposure, employee training, work practice changes, medical surveillance), and (4) personal protective equipment (e.g., respiratory protection, gloves, eye protection, hearing protection). Control banding, a qualitative risk assessment and risk management tool, is a complementary approach to protecting employee health. Control banding focuses on how broad categories of risk should be managed. Information on control banding is available at http://www.cdc.gov/niosh/topics/ctrlbanding/. This approach can be applied in situations where OELs have not been established or can be used to supplement existing OELs.

Below we provide the OELs and surface contamination limits for the compounds we measured, as well as a discussion of the potential health effects from exposure to these compounds.

Noise

Noise-induced hearing loss is an irreversible condition that progresses with noise exposure. It is caused by damage to the nerve cells of the inner ear and cannot be treated medically [Berger et al. 2003]. More than 22 million U.S. workers are estimated to be exposed to workplace noise levels above 85 dBA [Tak et al. 2009] and are at risk of noise-induced hearing loss [NIOSH 1998].

Although hearing ability commonly declines with age, exposure to excessive noise can increase the rate of hearing loss. In most cases, noise-induced hearing loss develops slowly from repeated exposure to noise over time, but the progression of hearing loss is typically the greatest during the first several years of noise exposure. Noise-induced hearing loss can also result from a single noise exposure or short duration noise exposures, depending on the intensity of the noise and the individual's susceptibility [Berger et al. 2003]. Noise exposed workers can develop substantial hearing loss before it is clearly recognized. Even mild hearing losses can impair a person's ability to understand speech and hear many important sounds. Some people with noise-induced hearing loss also develop "tinnitus." Tinnitus is a condition in which a person perceives hearing sound in one or both ears, but no external sound is present. Persons with tinnitus often describe hearing ringing, hissing, buzzing, whistling, clicking, or chirping like crickets. Currently, no cure for tinnitus exists.

The preferred unit for reporting of noise measurements is the dBA. A-weighting is used because it approximates the "equal loudness perception characteristics of human hearing for pure tones relative to a reference of 40 dB at a frequency of 1000 Hz" and is considered to provide a better estimation of hearing loss risk than using unweighted or other weighting measurements [Earshen 2003].

Employees exposed to noise should have baseline and yearly hearing tests to evaluate their hearing thresholds and determine whether their hearing has changed over time. Hearing testing should be done in a quiet location. In workplace hearing conservation programs, hearing thresholds must be measured at 500, 1000, 2000, 3000, 4000, and 6000 Hz. Additionally, NIOSH recommends that 8,000 Hz should also be tested [NIOSH 1998]. The OSHA hearing conservation standard requires analysis of changes from baseline hearing thresholds to determine if the changes are substantial enough to meet OSHA criteria for a standard threshold shift. OSHA defines a standard threshold shift as a change in hearing threshold relative to the baseline hearing test of an average of 10 dB or more at 2000, 3000, and 4000 Hz in either ear [29 CFR 1910.95]. If a standard threshold shift occurs, the company must determine if the hearing loss also meets the requirements to be recorded on the OSHA 300 Log of Injury and Illness [29 CFR 1904.1]. In contrast to OSHA, NIOSH defines a significant threshold shift as an increase in the hearing threshold level of 15 dB or more, relative to the baseline audiogram, at any test frequency in either ear measured twice in succession [NIOSH 1998].

NIOSH has an REL for noise of 85 dBA, as an 8-hour TWA. For calculating exposure limits, NIOSH uses a 3-dB time/intensity trading relationship, or exchange rate. Exposure to impulsive noise should never exceed 140 dBA. For extended work shifts NIOSH adjusts the REL. When noise exposures exceed the REL, NIOSH recommends the use of hearing protection and implementation of a hearing loss prevention program [NIOSH 1998].

The OSHA noise standard specifies a PEL of 90 dBA and an AL of 85 dBA, both as 8-hour TWAs. OSHA uses a less conservative 5-dB exchange rate for calculating the PEL and AL. Exposure to impulsive or impact noise must not exceed 140 dB peak noise level. OSHA does not adjust the PEL for extended work shifts. However, the AL is adjusted. OSHA requires implementation of a hearing conservation program when noise exposures exceed the AL [29 CFR 1910.95].

Lead

Inorganic lead is a naturally occurring, soft metal that has been mined and used in industry since ancient times. It comes in many forms (e.g., lead acetate, lead chloride, lead chromate, lead nitrate, lead oxide, lead phosphate, and lead sulfate). Lead is considered toxic to all organ systems and serves no useful purpose in the body.

Occupational exposure to inorganic lead occurs via inhalation of lead-containing dust and fume and ingestion of lead particles from contact with lead-contaminated surfaces. When careful attention to hygiene, particularly hand washing, is not practiced, smoking cigarettes or eating may create another route of exposure among workers who handle lead and then transfer it to their mouth through hand contamination. In addition to the inhalation and ingestion routes of exposure, lead can be absorbed through the skin [Stauber et al. 1994; Sun et al. 2002; Filon et al. 2006]. Workplace settings with exposure to lead and lead compounds include smelting and refining, scrap metal recovery, automobile radiator repair, construction and demolition (including abrasive blasting), and firing ranges. Occupational exposures also occur among workers who apply or remove lead-based paint and among welders who burn or torch-cut metal structures.

Blood Lead Levels

In most cases, an individual's blood lead level (BLL) is a good indication of recent exposure to lead because the half-life of lead (the time interval it takes for the quantity in the body to be reduced by half its initial value) is 1–2 months [Lauwerys and Hoet 2001; Moline and Landrigan 2005; CDC 2013a]. Most lead in the body is stored in the bones, with a half-life of years to decades. Measuring bone lead, however, is primarily done only for research. Elevated zinc protoporphyrin levels have also been used as an indicator of chronic lead intoxication; however, other factors, such as iron deficiency, can cause an elevated zinc protoporphyrin level, so monitoring the BLL over time is more specific for evaluating chronic occupational lead exposure.

BLLs in adults in the United States have declined consistently over time. In the last 10 years, the geometric mean BLL went from 1.75 micrograms per deciliter (µg/dL) to 1.23 µg/dL [CDC 2013b]. The NIOSH Adult Blood Lead Epidemiology and Surveillance System uses a surveillance case definition for an elevated BLL in adults of 10 µg/dL of blood or higher [CDC 2012a].

Occupational Exposure Limits

In the United States, employers in general industry are required by law to follow the OSHA lead standard (29 CFR 1910.1025). This standard was established in 1978 and has not yet been updated to reflect the current scientific knowledge regarding the health effects of lead exposure.

Under this standard, the PEL for airborne exposure to lead is 50 µg/m^3 of air for an 8-hour TWA. The standard requires lowering the PEL for shifts that exceed 8 hours, medical monitoring for employees exposed to airborne lead at or above the action level of 30 µg/m^3 (8-hour TWA), medical removal of employees whose average BLL is 50 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.

In the United States, other guidelines for lead exposure, which are not legally enforceable, are often followed. Similar to the OSHA lead standard, these guidelines were set years ago and have not yet been updated to reflect current scientific knowledge. NIOSH has an REL for lead of 50 µg/m^3 averaged over an 8-hour work shift [NIOSH 2010]. ACGIH has a TLV for lead of 50 µg/m^3 (8-hour TWA), with worker BLLs to be controlled to, or below, 30 µg/dL. The ACGIH designates lead as an animal carcinogen [ACGIH 2013]. More recently, the California Department of Public Health recommended that Cal/OSHA lower the PEL for lead to 0.5 to 2.1 µg/m^3 (8-hour TWA) to prevent BLLs at or above 5 to 10 µg/dL [Billingsley 2013].

Neither NIOSH nor OSHA has established surface contamination limits for lead in the workplace. The U.S. EPA and HUD limit lead on surfaces in public buildings and child-occupied housing to less than 40 micrograms of lead per square foot [EPA 1998; HUD 2012]. OSHA requires in its substance-specific standard for lead that all surfaces be maintained as free as practicable of accumulations of lead [29 CFR 1910.1025(h)(1)]. An employer with workplace exposures to lead must implement regular and effective cleaning of surfaces in areas such as change areas, storage facilities, and lunchroom/eating areas to ensure they are as free as practicable from lead contamination.

Health Effects

The PEL, REL, and TLV may prevent overt symptoms of lead poisoning, but do protect workers from lead’s contributions to conditions such as hypertension, renal dysfunction, and reproductive and cognitive effects [Schwartz and Hu 2007; Schwartz and Stewart 2007; Brown-Williams et al. 2009; IOM 2012]. Generally, acute lead poisoning with symptoms has been documented in persons having BLLs above 70 µg/dL. These BLLs are rare today in the United States, largely as a result of workplace controls put in place to comply with current OELs. When present, acute lead poisoning can cause myriad adverse health effects including abdominal pain, hemolytic anemia, and neuropathy. It has, in very rare cases, progressed to encephalopathy and coma [Moline and Landrigan 2005].

People with chronic lead poisoning, which is more likely at current exposure levels, may not have symptoms or they may have nonspecific symptoms that may not be recognized as being associated with lead exposure. These symptoms include headache, joint and muscle aches, weakness, fatigue, irritability, depression, constipation, anorexia, and abdominal discomfort [Moline and Landrigan 2005].

The National Toxicology Program recently released a monograph on the health effects of low-level lead exposure [NTP 2012]. For adults, the NTP concluded the following about the evidence regarding health effects of lead (Table A1).

Table A1. Evidence regarding health effects of lead in adults

Health area	NTP conclusion	Principal health effects	Blood lead evidence
Neurological	Sufficient	Increased incidence of essential tremor	Yes, < 10 µg/dL
	Limited	Psychiatric effects, decreased hearing, decreased cognitive function, increased incidence of amyotrophic lateral sclerosis	Yes, < 10 µg/dL
	Limited	Increased incidence of essential tremor	Yes, < 5 µg/dL
Immune	Inadequate		Unclear
Cardiovascular	Sufficient	Increased blood pressure and increased risk of hypertension	Yes, < 10 µg/dL
	Limited	Increased cardiovascular-related mortality and electrocardiography abnormalities	Yes, < 10 µg/dL
Renal	Sufficient	Decreased glomerular filtration rate	Yes, < 5 µg/dL
Reproductive	Sufficient	Women: reduced fetal growth	Yes, < 5 µg/dL
	Sufficient	Men: adverse changes in sperm parameters and increased time to pregnancy	Yes, ≥ 15–20 µg/dL
	Limited	Women: increase in spontaneous abortion and preterm birth	Yes, < 10 µg/dL
	Limited	Men: decreased fertility	Yes, ≥ 10 µg/dL
	Limited	Men: spontaneous abortion	Yes, ≥ 31 µg/dL
	Inadequate	Women and Men: stillbirth, endocrine effects, birth defects	Unclear

Various organizations have assessed the relationship between lead exposure and cancer. According to the Agency for Toxic Substances and Disease Registry [ATSDR 2007] and the National Toxicology Program [NTP 2012], inorganic lead compounds are reasonably anticipated to cause cancer in humans. The International Agency for Research on Cancer classifies inorganic lead as probably carcinogenic to humans [WHO 2006]. According to the American Cancer Society [ACS 2011], some studies show a relationship between lead exposure and lung cancer, but these results might be affected by exposure to cigarette smoking and arsenic; some studies show a relationship between lead and stomach cancer, and these findings are less likely to be affected by the other exposures. The results of studies looking at other cancers, including brain, kidney, bladder, colon, and rectum, are mixed.

Medical Management

To prevent acute and chronic health effects, a panel of experts published guidelines for the management of adult lead exposure [Kosnett et al. 2007]. The complete guidelines are available at http://www.cdph.ca.gov/programs/olppp/Documents/medmanagement.pdf. The panel recommended BLL testing for all lead-exposed employees, regardless of the airborne lead concentration. The panel's recommendations are outlined in Table A2. These recommendations do not apply to pregnant women, who should avoid BLLs > 5 µg/dL. Removal from lead exposure should be considered if control measures over an extended period do not decrease BLLs to < 10 µg/dL or an employee has a medical condition that would increase the risk of adverse health effects from lead exposure. These guidelines are endorsed by the California Department of Public Health [CDPH 2009], the Council of State and Territorial Epidemiologists [CSTE 2009], and the American College of Occupational and Environmental Medicine [ACOEM 2010]; and have been adapted for use by the U.S. Department of Defense [DOD 2007].

Table A2. Health-based medical surveillance recommendations for lead-exposed employees

Category of exposure	Recommendations
All lead exposed workers	• Baseline or preplacement medical history and physical examination, baseline BLL, and serum creatinine
BLL < 10 µg/dL	• BLL monthly for first 3 months placement, or upon change in task to higher exposure, then BLL every 6 months; if BLL increases ≥ 5 µg/dL, evaluate exposure and protective measures, and increase monitoring if indicated
BLL 10–19 µg/dL	• As above for BLL < 10 µg/dL, plus: BLL every 3 months; evaluate exposure, engineering controls, and work practices; consider removal. • Revert to BLL every 6 months after 3 BLLs < 10 µg/dL
BLL ≥ 20 µg/dL	• Remove from exposure if repeat BLL measured in 4 weeks remains ≥ 20 µg/dL, or if first BLL is ≥ 30 µg/dL • Monthly BLL testing • Consider return to work after 2 BLLs < 15 µg/dL a month apart, then monitor as above

Adapted from Kosnett et al. 2007

Take-home Contamination

Occupational exposures to lead can result in exposures to household members, including children, from take-home contamination. Take-home contamination occurs when lead dust is transferred from the workplace on employees' skin, clothing, shoes, and other personal items to their vehicle and home [CDC 2009; CDC 2012b].

The CDC considers a BLL in children of 5 µg/dL or higher as a reference level above which public health actions should be initiated, and states that no safe BLL in children has been identified [CDC 2013a].

The U.S. Congress passed the Workers' Family Protection Act in 1992 (29 U.S.C. 671a). The Act required NIOSH to study take-home contamination from workplace chemicals and substances, including lead. NIOSH found that take-home exposure is a widespread problem [NIOSH 1995]. Workplace measures effective in preventing take-home exposures were (1) reducing exposure in the workplace, (2) changing clothes before going home and leaving soiled clothing at work for laundering, (3) storing street clothes in areas separate from work clothes, (4) showering before leaving work, and (5) prohibiting removal of toxic substances or contaminated items from the workplace. NIOSH noted that preventing take-home exposure is critical because decontaminating homes and vehicles is not always effective. Normal house cleaning and laundry methods are inadequate, and decontamination can expose the people doing the cleaning and laundry.

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Availability of Report

Copies of this report have been sent to the employer, employees, and union at the facility. The state and local health department and the Occupational Safety and Health Administration Regional Office have also received a copy. This report is not copyrighted and may be freely reproduced.

This report is available at http://www.cdc.gov/niosh/hhe/reports/pdfs/2009-0216-3201.pdf.

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