Health Concern on Lead Encountered during Firing Practices: A Review

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ABSTRACT: Firing a gunshot leads to the expulsion of vapours and particulate materials termed gunshot residues (GSR) which includes particles of primer residue i.e. oxides of lead, antimony and barium as principle components. A fired bullet itself may contribute to lead particles or the particles of its jacket. Metallic lead or its oxide either airborne or deposited in soil and water followed by inhalation or ingestion by human beings would lead to chronic lead poisoning. Such poisoning has been shown to cause adverse effects in hematopoietic, nervous, endocrine, cardiovascular, reproductive and renal systems. Thus, airborne lead encountered during the routine firing practices is an increasing health concern for our security personnel. A number of reports and studies have been conducted emphasizing the risk of airborne lead exposure to the personnel at firing range. The effects of lead poisoning on the shooter depend on the dose and duration of exposure. The acute and chronic adverse health impacts due to lead exposure have been documented in the past. This paper emphasizes the measures that should be taken, especially by the police and army personnel involved in frequent firing practices including the introduction of lead free ammunition, proper ventilation system at firing range, wearing suitable personal protective equipments, proper personal and occupational hygiene and behaviours. Issues regarding the environment at firing range to minimize the exposure potential and the importance of contaminated site remediation are also emphasized.

Keywords: airborne lead or lead oxide, heavy metal, gunshot residues, firing range, protection of security personnel

Introduction

Ammunition is predominantly used in a localized area when men in armed forces undergo firing training leading to accumulation of the products of discharge from firearms, viz. vapours and particulate materials. Such discharged products collectively known as gunshot residues (GSR) (Meng and Caddy, 1997; Romolo and margot, 2002) are formed by rapid cooling of gases from extreme temperatures and pressure (Basu, 1982). Thus, gunshot residues are principally composed of burnt and unburned particles from the gun powder and the primer, as well as the particulate materials from the bullet, cartridge case and firearm itself due to friction all of which would be dispersed in to the atmosphere as well on the person shooting the firearm (Meng and Caddy, 1997; Romolo and margot, 2002).

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Primer is the mixture of high sensitive explosive materials in ammunition. Initiated by the mechanical force of the striking by the firing pin, the primer mixture will explode causing a jet of flame thus ignites the propellant i.e. the smokeless powder propelling the bullet. Common primer mixtures include compounds of lead, antimony and barium (Meng and Caddy, 1997; Romolo and margot, 2002; Basu, 1982, Garofano et al., 1999; Martiny et al., 2008). In primer, there are also other elements which are often found to be associated with gunshot residues including copper, iron, as well as other non-specific elements such as silicon, aluminium, potassium, calcium and sulfur (Meng and Caddy, 1997; Garofano et al., 1999). Lead bullets or their metal jackets also contribute to particles of corresponding metal (Martiny et al., 2008; Wolten and Nesbitt, 1980)

Rapid heating and confined pressurization during cartridge discharge lead to aerosolized accumulation of heavy metals (Meng and Caddy, 1997; Romolo and margot, 2002; Basu, 1982). As mentioned by Basu (1982), the primer temperature exceeds the vapourization points of lead (1620^{o}C), antimony (1380^{o}C) and barium (1140^{o}C) within fraction of millisecond. Due to supersaturation, the primer vapours often condense and liquefy onto the primer surface as droplets which have a characteristic morphology and chemical composition (Basu, 1982; Quinn, 1988). This paper reviews the heavy metals in gunshot residues, particularly the inorganic lead and its health effects, the fate of lead when released to environment and means to minimize form its exposure.

Source and health effect on lead exposure

The metal lead (Pb) is poisonous to human. Center for Disease Control and Prevention (CDC, 1991) reports that lead poisoning is one of the most common and preventable pediatric health problems nowadays (CDC, 1995). The half-life of lead in blood and soft tissues is about 28 to 36 days but it is much longer in bone compartments. Lead retention is much higher in children as compared to adults (WHO, 2005). Lead contamination is a public health problem of world-wide scope affecting the health of especially women and children (Mormontoy, 2001). It gives a more significant adverse effects to fetuses and young children (CDC, 1995) as it damages the body systems that are still in developing stage (Carra, 1995).

National Institute for Occupational Safety and Health (NIOSH) literature reviewed the health effects due to inorganic lead exposure (NIOSH, 2001). Lead has been shown to cause adverse effects in hematopoietic, nervous, endocrine, cardiovascular, reproductive and renal systems (CDC, 1995; Taylor et al., 2007). Lead has direct toxic effects on tissues and interferes with high affinity metal-binding protein and enzymes in human body (Martiny et al., 2008; Taylor et al. 2007). There was evidence showing the adverse effects of lead on the adult reproductive, cardiovascular, hematologic systems and on the children of lead exposed workers even at blood lead levels as low as 10 µg/dL. Additionally, over-exposure to lead may also result in damage to the kidneys, anemia, high blood pressure, impotence, and infertility and reduced sex drive in both sexes (NIOSH, 2001). It is also classified as a group B2 substance (probable human carcinogen) by US Environmental Protection Agency (USEPA), exhibiting a possibility of cancer when ingested or inhaled (ATSDR, 2009). The Permissible Exposure Level (PEL) for lead in workplace air prescribed by the Occupational Safety and Health Administration (OSHA) is 50 $\mu g/m^3$ based on 8-hr time-weighted average (TWA) (ATSDR, 2009). Note that PEL's for both antimony and barium (as soluble barium compound) are 500 $\mu g/m^3$ based on 8-hr TWA (ATSDR, 1992; ATSDR, 2007).

Sources of lead intake include food, water and dust, as well as direct inhalation (Davidson and Rabinowitz, 1992). Indoor dust represents a highly variable and mobile source of lead exposure. The rate of uptake of environmental lead by humans depends on the route of exposure. Generally, inhalation of airborne lead may result in absorption rate of about 50% whereas absorption of ingested lead approaches 10% (WHO, 1995). Moreover, such rates will be greater during lead uptake by infants or nutritionally deficient individuals (Davidson and Rabinowitz, 1992). Once lead is absorbed, it is not distributed homogenously throughout the body; it is rapid in blood and soft tissues and slower in bone (WHO, 1995). Direct contact with such metal through environmental and occupational exposure may damage normal body function. Duration and level of exposure correspondingly increase the biological effects at the cellular level and overall functioning of the body in human (WHO, 1995) and therefore preventative actions to occupational lead exposure must be taken by parties concerned.

Blood lead levels (BLL) are used to measure the absorbed doses of lead. 10 µg/dL is the level of concern set by CDC in year 1991 which was a significantly lower level of 25 µg/dL set before (CDC, 2005). Elevated zinc protoporphyrin (ZPP) levels have been used as an indicator of chronic lead intoxication. Persons without occupational lead exposure usually have a ZPP level less than 40 µg/dL (NIOSH, 2001). The level of lead in drinking water is usually below 5 µg/L (WHO, 1995; Davidson and Rabinowitz, 1992). However, high level of concentration as high as 300 µg/L can be achieved with contact on lead bearing pipes, solder and plumbing fixtures (WHO, 1995) and this certainly worth attention by the authorities concerned as lead bearing pipes and plumbing fixtures are still prevalent in old residential structures.

Lead exposure in firing practices

Due to the physical properties of lead with low melting point, corrosion resistance, malleability and high density, it is used in a wide variety of industries and trades (WHO, 1995; Matte et al., 2002). Ammunition manufacture is one of the major industrial uses of lead as priming compounds or bullets with an estimated consumption of about 5% (approximately 141,000 tonnes) of the global lead by the ammunition industry (Matte et al., 2002).

Airborne lead encountered during the usage of firearms can be a health concern for frequent firearm user or indoor firing range employees because considerable amounts of toxic and hazardous vapours are produced in firing practice.

Airborne lead fume and dust are generated by hot propellant gases, friction of bullets in the gun barrel, fragmentation of bullets striking the target and by the combustion of lead in priming compounds (Novotny et al, 1987; Svensson et al., 1992; Matte et al., 2002). These lead vapours may enter bloodstream via inhalation and lead to elevated blood lead level (Matte et al., 2002).

Novotny et al. (1987) emphasized the risk of airborne lead exposure in employees of firing ranges (Novotny et al, 1987). Blood lead levels in employees at one range varied from 41 to 77 µg/dL and air lead level from 14 to 91 µg/m^3 (Matte et al., 2002). A Swedish study showed that the blood lead levels among police officers positively correlated with the number of bullets annually fired while there was a slightly negative association with the time since last firing practice (Lofstedt et al, 1999). Abudhaise et al. (1996) found a higher concentration of air lead measure that markedly exceeded the internationally adopted safe exposure level and a significantly higher blood lead levels in the instructors and trainees as compared to control (Abudhaise et al., 1996). In addition, the activity of amino levulinic acid dehydrogenase (ALAD) was also significantly reduced indicating the subcritical effect of lead (Abudhaise et al., 1996). Study conducted by Demmeler et al. (2009) showed that indoor shooting may cause very high blood lead concentrations in subjects using calibre .22 lr (long rifle) weapons or large caliber handguns (Demmeler et al., 2009).

Cartridge maker and gun barrel browner are the occupations that are potentially proned for lead exposure (Matte et al., 2002) too. Dedicated shooters, instructors and employees, as well as military and law enforcement personnel are at risk of exposure to lead contamination (Charpentier and Desrochers, 2000; Martiny et al., 2008). Additionally, citizens who practice target shooting as leisure activity are also potentially exposed to lead where such activity is increasingly popular (Ochsmann, 2009). Shooting with lead-containing ammunition is considered to be the source of lead uptake (Svensson et al., 1992) Therefore, effort to reduce lead to a minimum in products is important.

Fate of lead at shooting ranges

At shooting ranges, lead dust and debris are generated at firing line and bullets are trapped at bullet stops or may end up in soils (Chen et al., 2002; Levonmaki et al., 2006). Weathering of bullets led to accumulation of lead in soil (Cao et al., 2003). The weathering process occurs at all time and results in the accumulation of lead in soil. Studies show that total concentration of lead in surface soils is significantly elevated at shooting range (Chen et al., 2002; Cao et al., 2003). Though the distribution of lead concentration varied in the surface soils of different shooting ranges, soils with high accumulation of bullets give rise to higher concentration of lead. The rate of weathering and the products are highly variable and site specific (Chen et al., 2002; Cao et al., 2003).

Subsequent chemical reaction rates of lead depending on soil properties, contact time and climate (Cao et al., 2003; Johnson et al., 2005; Levonmaki et al., 2006). Lead carbonate or cerussite ($PbCO_3$), hydrocerussite [$Pb(CO_3)_2(OH)_2$] and lead sulfate or anglesite ($PbSO_4$) are some of the products (Cao et al., 2003). Further reactions will lead to the transformation into dissolved and particulate species and enter the environment through dissolution and subsequently leaching (Cao et al., 2003). Chen et al. (2002) suggested that the removal of lead bullets by sieving if the soil was highly contaminated with lead (Chen et al., 2002). Although lead is found concentrated on the soil surface at shooting range and soil remediation can be an option to prevent it from contaminating groundwater, care must be taken to ensure that remediation is thorough since low concentration of lead did not eliminate the possibility of lead leaching into ground water (Ryu et al., 2007).

Several factors affect subsequent distribution of lead when released to soil. Soil organic matters are important in transporting lead from the surface to subsurface (Chen et al., 2002; Cao et al., 2003; Johnson et al., 2005; Levonmaki et al., 2006). High rainfall and shallow groundwater level contributes also to the high amounts of accumulated lead (Chen et al., 2002). Lead is found to be more soluble in acidic or low pH condition as compared to neutral and alkaline conditions. Apart from that, the total concentration of lead increases also with the operation period of shooting ranges (Cao et al., 2003). Situations of shooting ranges adjacent to environmentally sensitive wetlands were also reported as one of the factors on increased amount on lead (Chen et al., 2002). Lead level in water could be elevated with lead shot erosion (Astrup et al., 1999; Cao et al., 2003). The amount of lead uptake is increased with the concentration of lead in soil. Such condition could potentially increase wildlife exposure to lead due to the vegetations that serve as attractive habitat and food (Cao et al., 2003; Levonmaki et al., 2006).

Minimizing exposure potential

Lead contamination is harmful is someone if in contact. The primer as well as the projectile is the two main sources of airborne lead. For the shooters, 80% of airborne lead on a firing range originates from the projectile while the remaining 20% comes from the combustion of the primer mixture (Charpentier and Desrochers, 2000). However, the latter is more hazardous due to the formation of finer particles size as compared to those scrubbed from the bullet surfaces because these finer particles have greater absorption rate through the respiratory tract.

The health concern related to the use of lead during shooting leads to the development of lead free ammunition. Banning of lead containing ammunition would be the most effective measure for prevention. Such ammunition avoids the evolvement of toxic gases and eliminates hazardous airborne lead particulates from the primer compositions and bullet itself (Gunaratnam, Himberg, 1994; Harris, 1995; Charpentier and Desrochers, 2000; Oommen and Pierce, 2006; Martiny et al., 2008). Lead styphnate in primer mixture is being replaced to some extent with some other metal formulations such as strontium. Apart from that, the reduced airborne lead ammunitions are also modified by enclosing the base of the projectile as well as the entire projectile with brass, copper or gilding metal. Fabrication of projectile is also carried out with sintered metal not containing lead (Oommen and Pierce, 2006). The combination of a lead free primer and fully jacketed bullets is intended to eliminate hazardous airborne lead particulates and is being marketed for use in indoor firing ranges around the world (Matte et al., 1992; Harris, 1995, Demmeler et al., 2009).

Continued use of jacketed bullets and non-lead priming are also recommended by NIOSH (2001). As reported (NIOSH, 2001), no health hazard was presented in officers in training and range instructors from the firing of copper-jacketed lead-free primer ammunition but continued use of conventional ammunition may expose those users to lead and result in further surface contamination. Malaysian security forces today are still using traditional ammunition with the presence of lead components. In this regard, considering the health concerns, introduction of more lead free ammunition is desired in the future. Studies also suggested that ammunition higher than .22 caliber should be limited in firing practice given that higher concentration of airborne lead is found to be produced with higher caliber ammunition (Schaeffer, 1990).

At shooting ranges, inadequate ventilation at a firing range and failure to use personal protective equipment the employees may result in lead poisoning of exposed employees (Novotny et al., 1987). Proper ventilation system is recommended to be used to control the exposure to lead in addition to regular check up on the system. The high level of lead in air may be lowered by improved ventilation on the range (Schaeffer et al., 1990; Matte et al., 1992; Svensson et al., 1992; Lofstedt et al., 1999 Ochsmann et al., 2009; Demmeler et al., 2009). The use of dedicated air supply and exhausted system with ports for the venting of particle-laden air away from the personnel could minimize the exposure potential. In addition, the development of control booths, installation of floor drains and waste traps used for cleaning up are recommended (Schaeffer et al., 1990) Recommendations on negative pressurization of the range and adequate airflow throughout the range in an uniform manner from the firing line to the bullet trap has been suggested (NIOSH, 2001). Wearing adequate dust masks could probably reduce exposure effectively (Ochsmann et al., 2009).

Target retrieval systems are recommended to reduce the chance of tracking of lead contaminated dust to other area out of the range or personal's clothing (Ochsmann et al., 2009). Although the stop butt did not constitute to a significant risk to the environment due to lead as studied by Astrup et al. (1999), the soil in the embankment has to be handled as hazardous waste with highly polluted lead (Astrup et al., 1999). Removal of such polluted soil has to be conducted according to standard procedure if it is removed from the facility or abundant of facility (Astrup et al., 1999). Precautionary measures should also be taken while mowing the grass at firing range in order to minimize the exposure of airborne lead to the workers (Cao et al., 2003). Range personnel should also be rotated if possible in order to prevent prolonged duty with extended period of potential lead exposure at that assignment (Schaeffer et al., 1990).

As mentioned by Schaeffer et al. (1990), education always is the key for an effective prevention program. Range managers, operators and users should understand the potential hazard due to exposure of lead and how their actions can lower the risk factors at the range (Schaeffer et al., 1990). Proper hygiene practices and safe use of all of the ranges were also presented in the report by NIOSH in 2001 (NIOSH, 2001). Periodic biological monitoring of the frequent users of firing ranges is recommended. Assessment of the level of internal exposure to harmful agents and the presence of early toxic effects has been suggested (Taylor et al., 2007). Additionally, environmental hygiene actions in order to control the excessive emission of lead on the range have also been indicated as imperative (Abudhaise et al., 1996). Environmental monitoring, biological monitoring and health surveillance are important and well established tools on the assessment of risk due to harmful chemical agents including lead (Taylor et al., 2007). Guidelines published NIOSH for the construction, maintenance and monitoring of firing ranges should be followed (NIOSH, 1975).

At contaminated shooting ranges, risk assessment of lead is important as quantitative evaluation of adverse effects and also decision making of environmental management (Ryu et al., 2007). Lead has a higher affinity on certain mineral surfaces as compared to organic matters (Levonmaki et al., 2006). Hence, phosphate levels are crucial in the lead solubility control due to highly insolubility of lead phosphates. In situ chemical remediation technology is proved to reduce cost and environmental impacts in treatment of metal-contaminated soils (Hashimoto et al., 2009). In situ lead stabilization through phosphate amendment is a cost effective method from previous measures being taken in order to reduce the effects of lead in shooting range soils (Cao et al., 2003; Dermatas et al., 2008). The treatment of lead by phosphate on contaminated soils highly relies on the premise as lead is converted into thermodynamically stable, insoluble class of pyromorphites or lead phosphates (Dermatas et al., 2008). Hashimoto et al. (2009) suggested also the combination usage of amendments along with plant growth in order to enable the immobilization of lead in increment of dehydrogenase and phosphatase activities as well as restoration of soil (Hashimoto et al., 2009).

Conclusion

Airborne lead encountered during firing practices is an increasing health concern especially for those who work in the firing range and those who shoot frequently. Exposure to lead may cause adverse effects in normal body functioning. However, the public awareness in Malaysia might still be low and potential adverse effects by lead contamination appear to have been neglected. Malaysian law enforcements such as police and army today are still dealing with the usage of conventional ammunition with lead as priming component and bullet material. Studies on the quantum of lead, gaseous and particulate in indoor and open firing ranges in Malaysia would throw specific light on the extent of lead contamination to which our security personnel are exposed. Measures should be taken by parties concerned for the health of the personnel. Environmental monitoring, biological monitoring and health surveillance are important on the assessment of risk due to harmful and toxic lead metal especially to the personnel with long exposure time using lead containing ammunition for training or routine shooting range maintaining operation. Introduction of more lead free ammunition should be encouraged in the future along with proper systems at firing ranges in Malaysia especially at indoors.

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