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English summary

The background for this investigation is the health related problems experienced by some units of the Norwegian Armed Forces after the introduction of so-called “non-leaded” ammunition for small arms. These problems were relatively rare, but still they created a major problem for those persons and the units involved.

The health problems correspond to symptoms typical for metal fever. The symptoms experienced were nausea, sore throat, joint pains, headache, flu symptoms, dizziness, chills, light fever, laxity, etc. The user of the weapon would typically experience the problems a few hours after finishing the firing. The symptoms lasted for some hours, but would then cease without leaving any long term effects. Usually the user was quite fit on the morning after the firing.

Metal fever would indicate that the reason for the problems is the metallic content in the dust that is emitted from the weapon. However, it could not be excluded that some gases in the propellant combustion products could contribute to the problems. Thus, both metals and a few poisonous gases were subject to analyses.

The compounds emitted from the weapon are not exclusively coming from the muzzle. Some gas and dust may also be emitted through the chamber opening and the reloading mechanism in an automatic or semiautomatic weapon.

This report is a documentation of those tests in the program that can be rated as unclassified. Thus, only tests with commercially available ammunition are mentioned here. In addition, some tests on unqualified and experimental ammunition were also made. These tests eventually led to the development of modified ammunition, which significantly reduced the rate of emission. These results are documented in a classified Norwegian report.

This unclassified report is made for the ERM project (Environmentally Responsible Munitions) of the European Defence Agency.

Sammendrag

Denne rapporten er en dokumentasjon av de støv- og avgassmålinger som ble gjort i forbindelse med prosjekt 1204 Ny miljøammunisjon. Bakgrunnen for dette prosjektet var de problemene som var oppstått ved bruk av den blyfrie 5,56 mm ammunisjonen NM229 i form av helseplager blant brukerne.

Alle målingene ble gjort i en dertil laget beholder som fanger opp alle gasser og alt støv som kommer ut av våpenet, det vil si fra munning, fra det gassdrevne ladesystemet og fra utkasteråpningen.
De gassene som ble målt, var kullos/karbonmonoksid (CO), ammoniakk (NH_3) og blåsyregass/hydrogencyanid (HCN). Disse tre gassene, som alle har en viss giftighet, ble ansett som de alvorligste. Andre gasser slippes også ut, men er enten ufarlige eller antas å finnes i ubetydelige mengder.

De fleste målingene ble gjort med 5,56 mm kaliber, men det er også gjort en del målinger for 7,62 mm, 9 mm og 4,6 mm.

På bakgrunn av disse målingene ble geometrien til ammunisjonen modifisert av NAMMO, og en ny standardammunisjon, kalt NM255, ble innført. Denne ammunisjon har mindre utslipp av NH_3 og HCN på grunn av et nytt krutt, og et utslipp av kopper og sink som er kun litt høyere enn utslippet fra tradisjonell blyholdig ammunisjon. Dog er utslippet av kopper fremdeles betydelig, hvilket det også har vært for blyholdig ammunisjon.

Det siste kapitlet i rapporten er et bidrag til en forklaringsmodell for utslippet. Her trekkes det sammenligninger mellom utslippet av metall for forskjellige våpen med 5,56 mm kaliber. Løpsprofilen for slike våpen ble målt, og det kan påvises en korrelasjon mellom utslippsmengden og hvor trangt løpet er.

Rapporten gir resultatene fra målinger gjort med kommersielt tilgjengelig ammunisjon. Disse og øvrige resultater fra måleseriene er presentert i en gradert FFI-rapport.

Contents

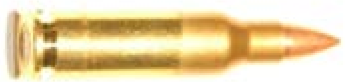
1 Introduction

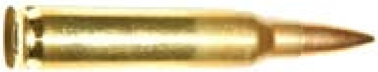
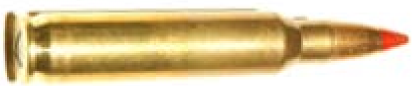
This report documents the results of the measurements of dust and gas made when firing different weapons with different ammunition at FFI in 2011 and 2012. The measurements consisted of sampling of carbon monoxide, ammonia and hydrogen cyanide, and analyses of the content and composition of metals in the dust emitted from the weapon. The procedures performed during the firing, and the chemical preparations before the analyses of the dust composition could be made, are documented. In the aftermath of these tests, in search for an explanation to the results, a measurement of the bore profile were made on a selection of the weapons. These profiles were compared with the amount of dust emission. These two factors seem to be correlated.

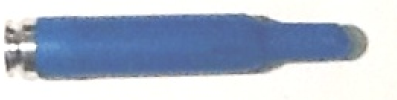
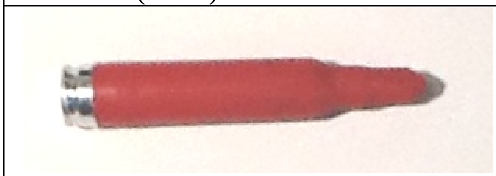
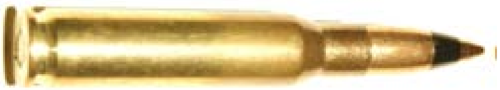
2 Ammunition

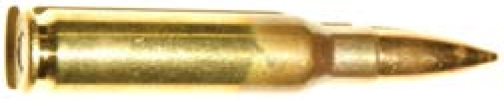
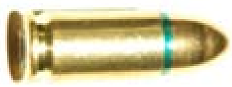
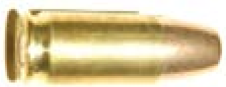
The tests that are documented herein are all done with commercially available ammunition. All calibers, i. e. 4.6 x 30 mm, 5.56 x 45 mm, 7.62 x 51 mm and 9 x 19 mm, are covered.

The ammunitions used are presented in the table below.

DM11	Manufacturer	RUAG
	Caliber	4.6 mm (meas. 4.61)
	Total length	38.25 mm
	Mass	6.85 g
	Propellant	0.53 g ball powder
	Primer	Sintox
	Projectile	2.0 g massive steel
BNT2 HP	Manufacturer	NAMMO
	Caliber	4.6 mm (meas. 4.62)
	Total length	38.25 mm
	Mass	2.0 g
	Propellant	PBC 749 0.55 g ball powder
	Primer	Sintox
	Projectile	2.0 g massive steel
M193	Manufacturer	ATK
	Caliber	5.56 mm
	Total length	57.11mm
	Mass	11.56 g
	Propellant	1.82 g ball powder
	Primer	Sinoxid
	Projectile	3.55 g w/lead core
M855	Manufacturer	Lake City
	Caliber	5.56 mm (meas. 5.70)
	Total length	57.13
	Mass	11.98 g
	Propellant	1.73 g ball powder
	Primer	
	Projectile	4.04 g steel tip core, lead main core, green tip

SS109	Manufacturer	RUAG
	Caliber	5.56 mm (meas. 5.69)
	Total length	57.23 mm
	Mass	12.34 g
	Propellant	1.69 g ball
	Primer	Sinoxid
	Projectile	4.02 g steel tip core, lead main core
DT4	Manufacturer	NAMMO
	Caliber	5.56 mm (meas. 5.70)
	Total length	57.02 mm
	Mass	3.90 g
	Propellant	1.72 g ball
	Primer	
	Projectile	2.2 g lead core, barium charge, violet tip
AP3 /M995	Manufacturer	NAMMO
	Caliber	5.56 mm
	Total length	57.02 mm
	Mass	11.8 g
	Propellant	1.84 g ball powder
	Primer	
	Projectile	3.45 g WC core, black tip
SS109 SELF	Manufacturer	RUAG
	Caliber	5.56 mm
	Total length	57.46 mm
	Mass	12.19 g
	Propellant	SMP
	Primer	Sintox
	Projectile	4.0 g steel tip core, hollow copper main core
NM229	Manufacturer	NAMMO
	Caliber	5.56 mm
	Total length	57.11 mm
	Mass	12.38 g
	Propellant	St Marks 1.6 g ball powder
	Primer	RUAG Sintox
	Projectile	4.00 g dual steel core
NM230	Manufacturer	NAMMO
	Caliber	5.56 mm
	Total length	57.12 mm
	Mass	
	Propellant	1.64 g SMP ball
	Primer	Sintox
	Projectile	3.65 g copper core, orange tip
Frangible	Manufacturer	Federal
	Caliber	5.56 mm
	Total length	55.98 mm
	Mass	10.98 g
	Propellant	1.71 g ball owder
	Primer	
	Projectile	2.91 g m/sintered copper alloy(?)

Frangible	Manufacturer	ICC
	Caliber	5.56 mm
	Total length	56.00 mm
	Mass	10.84 g
	Propellant	1.56 g extruded
	Primer	
	Projectile	2.68 g sintered copper
NM250 (Short range)	Manufacturer	NAMMO
	Caliber	5.56 mm
	Total length	51.9 mm
	Mass	3.12 g
	Propellant	0.52 g extruded
	Primer	
	Projectile	0.29 g massive plastic
NM226F1 (Blank)	Manufacturer	NAMMO
	Caliber	5.56 mm
	Total length	53.2 mm
	Mass	3.0 g
	Propellant	0.43 g extruded
	Primer	
	Projectile	-
M43	Manufacturer	Soviet arsenals
	Caliber	7.62 mm x 39
	Total length	
	Mass	23.54 g
	Propellant	
	Primer	
	Projectile	
NM60 / NM223	Manufacturer	NAMMO
	Caliber	7.62 mm (meas. 7.81)
	Total length	
	Mass	23.54 g
	Propellant	2.67 g extruded
	Primer	
	Projectile	9.45 g lead core
NM62 / NM224	Manufacturer	NAMMO
	Caliber	7.62 mm (meas. 7.82)
	Total length	70.88 mm
	Mass	23.19 g
	Propellant	2.86 g extruded
	Primer	
	Projectile	9.10 g g lead core, strontium charge, red/orange tip
AP8	Manufacturer	NAMMO
	Caliber	7.62 mm
	Total length	70.94 mm
	Mass	23.60 g
	Propellant	2.89 g extruded
	Primer	
	Projectile	WC (tungsten carbide) core

NM231	Manufacturer	NAMMO
	Caliber	7.62 mm
	Total length	71 mm
	Mass	23.25 g
	Propellant	2.70 g extruded
	Primer	
	Projectile	9.00 g m/dual steel core
NM232	Manufacturer	NAMMO
	Caliber	7.62 mm
	Total length	70.91 mm
	Mass	22.97 g
	Propellant	2.77 g extruded
	Primer	
	Projectile	8.70 g lead core, strontium charge
Parabellum GFL	Manufacturer	Fiocchi
	Caliber	9 mm
	Total length	20.34 mm
	Mass	11.81 g
	Propellant	0.39 g ball
	Primer	
	Projectile	7.44 g lead core
NM233	Manufacturer	NAMMO
	Caliber	9 mm
	Total length	29.31 mm
	Mass	11.56 g
	Propellant	0.4 g ball
	Primer	
	Projectile	7.3 g steel jacket, copper core
(NM233)	Manufacturer	NAMMO
	Caliber	9 mm
	Total length	29.62 mm
	Mass	11.48 g
	Propellant	0.42 g ball
	Primer	
	Projectile	7.02 g copper jacket and core
Frangible	Manufacturer	Speer
	Caliber	9 mm
	Total length	28.18 mm
	Mass	10.8 g
	Propellant	0.41 g ball
	Primer	
	Projectile	6. 5 g sintered copper

3 Weapons

The health problems that were observed and which is the reason for this work, started shortly after introduction of HK416 as the standard small arms in the Norwegian Army. Thus we cannot exclude the possibility that the use of this new weapon is a factor contributing to the emission of gas and dust. It was therefore necessary to do emission tests with different weapons of the same caliber.

Those weapons that were tested are shown in the table below, together with some basic data. Most of the weapons belong to the FFI inventory and some have been borrowed from the armed forces.

MP7	Manufacturer	Heckler & Koch
	Caliber	4.6 x 30 mm
	Barrel length	180 mm
	Weight	1.2 kg
	Twist length	160 mm
	Notes	So far, this is the only weapon with this caliber
HK416K	Manufacturer	Heckler & Koch
	Caliber	5.56 x 45 mm
	Barrel length	267 mm
	Weight	3.02 kg
	Twist length	178 mm
	Notes	
HK416N	Manufacturer	Heckler & Koch
	Caliber	5.56 x 45 mm
	Barrel length	419 mm
	Weight	3.56 kg
	Twist length	178 mm
	Notes	
G36 C	Manufacturer	Heckler & Koch
	Caliber	5.56 x 45 mm
	Barrel length	228 mm
	Weight	2.96 kg
	Twist length	178 mm
	Notes	
C8 SFW	Manufacturer	Diemaco / Colt Canada
	Caliber	5.56 x 45 mm
	Barrel length	368 mm
	Weight	2.68 kg
	Twist length	178 mm
	Notes	
C8 CQB	Manufacturer	Diemaco / Colt Canada
	Caliber	5.56 x 45 mm
	Barrel length	250 mm
	Weight	2.7 kg
	Twist length	178 mm
	Notes	

F2000	Manufacturer	FN Herstal
	Caliber	5.56 x 45 mm
	Barrel length	400 mm
	Weight	3.6 kg
	Twist length	178 mm
	Notes	
AUG	Manufacturer	Steyr Mannlicher
	Caliber	5.56 x 45 mm
	Barrel length	508 mm
	Weight	3.6 kg
	Twist length	229 mm
	Notes	
M16 A1	Manufacturer	Colt
	Caliber	5.56 x 45 mm
	Barrel length	508 mm
	Weight	4.0 kg
	Twist length	305 mm
	Notes	
LMG Minimi	Manufacturer	FN Herstal
	Caliber	5.56 x 45 mm
	Barrel length	465 m
	Weight	6.85 kg
	Twist length	178 mm
	Notes	
FN MAG	Manufacturer	FN Herstal
	Caliber	7.61 x 51 mm
	Barrel length	630 mm
	Weight	11.8 kg
	Twist length	305 mm
	Notes	
MG3	Manufacturer	Rheinmetall GmbH
	Caliber	7.61 x 51 mm
	Barrel length	565 mm
	Weight	10.5 kg
	Twist length	305 mm
	Notes	Rifled bore
MG3	Manufacturer	Rheinmetall GmbH
	Caliber	7.61 x 51 mm
	Barrel length	565 mm
	Weight	10.5 kg
	Twist length	305 mm
	Notes	Polygonic bore
AG 3	Manufacturer	Heckler & Koch
	Caliber	7.61 x 51 mm
	Barrel length	450 mm
	Weight	4.1 kg
	Twist length	305 mm
	Notes	

HK417 S	Manufacturer	Heckler & Koch
	Caliber	7.61 x 51 mm
	Barrel length	508 mm
	Weight	4.23 kg
	Twist length	280 mm
	Notes	
MP5	Manufacturer	Heckler & Koch
	Caliber	9 x 19 mm
	Barrel length	225 mm ?
	Weight	2.7 kg
	Twist length	250 mm
	Notes	
P80	Manufacturer	Glock GmbH
	Caliber	9 x 19 mm
	Barrel length	114 mm
	Weight	0.62 kg
	Twist length	250 mm
	Notes	

4 Standards

The table below shows the basic parameters for 5.56 mm, 7.62 mm and 9 mm as defined in the NATO STANAGs. Some derived parameters are also included. No STANAG yet exists for the 4.6 mm. The numbers shown below for that ammunition are taken from various open sources.

*Table 4.1 Basic properties of the different calibers *Volume without any bullet inserted*

Caliber (mm)	**4.6**	**5.56**	**7.62**	**9.0**
STANAG no.	-	4172	2310	4090
Cartridge length (mm)	30	44.7	51.2	19.2
Max. Cartridge diameter (mm)	8.02	9.55	11.9	9.9
Cartridge volume (cm^3)*	0.87	1.82	3.47	0.86
Proj. length outside cartridge (mm)	8.3	12.7	20.2	9.5
Standard projectile weight (g)	2	~ 4 g	8.4 – 10.0	7.0 – 8.3
Muzzle energy (J)	420 - 540	> 1500	> 2915	542 - 814
Min. extraction force (N)	unknown	200	265	200
Max. chamber pressure (MPa)	400	420	380	265
No. of grooves	6	6	4	6
Twist length (mm)	160	178	305	254
Diameter across lands (mm)	4.52	5.56	7.62	8.79
Height of lands (mm)	0.065	0.065	0.10	0.115
Width of grooves (mm)	3.52	1.88	4.47	2.54
Projectile diameter (mm)	4.67	5.626-5.702	7.773-7.849	8.954-9.030
Bore cross section (mm^2)	16.52	25.032	47.483	62.387
Cross section ratio (bore/projectile)	0.964	0.980-1.007	0.981-1.001	0.974-0.991

It is worth noticing that the bore cross section is usually less than the cross section of the projectile. Consequently, the projectile has to deform or erode to get through the barrel.

5 Experimental setup

5.1 Firing procedure

The main purpose of these tests was to show how the emission of different gases and metals depends on the weapon used and the ammunition fired. It was also important to measure the emission from the weapon as a whole, and not only from the muzzle. Any emission from the ejection port and the reloading mechanism may potentially be more harmful for the user than the muzzle emission.

Consequently the firings had to be done in a chamber with the following characteristics

- the chamber should contain the whole weapon
- the chamber should be not too large to avoid diluting the emitted compounds too much
- the chamber should be as air tight as possible
- the chamber should have some flexibility in order to sustain the shock waves and avoid too much overpressure
- the projectile has to exit the chamber with a minimum of leakage
- the chamber should minimize the need for cleansing after each firing sequence

In addition it was important to have a setup that could give results within a reasonable time and that the measurements could be made consistently.

The firing chamber consisted of two separate rigid circular aluminium plates with a 1 m diameter. Each plate was supported by two simple aluminium legs. The plates form the ends of a cylindrical chamber. The cylindrical surface was made of a disposable and transparent polyethylene sheet of the type that is used as humidity barrier in houses. The sheet was 0.15 mm thick. The sheet was strapped onto the end plates by ropes that were tightened into grooves cut into the cylindrical edges of the plates. The rear end plate had a support arm for the weapon. The fixation of the weapon had to be done individually according to the presence of Picatinny-rails or other fixtures. In the rear plate there was also an opening for operating the weapon. To avoid any leakage during firing, this opening was closed by a rectal glove.[1] In the rear plate there was also a small hole that could be used for remote firing of the weapon in the cases where the ammunition was considered unsafe. Normally, the weapon was operated through the glove. The total volume of the chamber is adjustable, but in most cases a volume of 1.0 m^3 was used. However, in some cases, when long barreled weapons were used, the distance between the plates had to be increased.

[1] A rectal glove is a thin, disposable glove covering 80% of the arm and is used during veterinary examinations of large domestic animals.

A picture of the chamber is shown below.

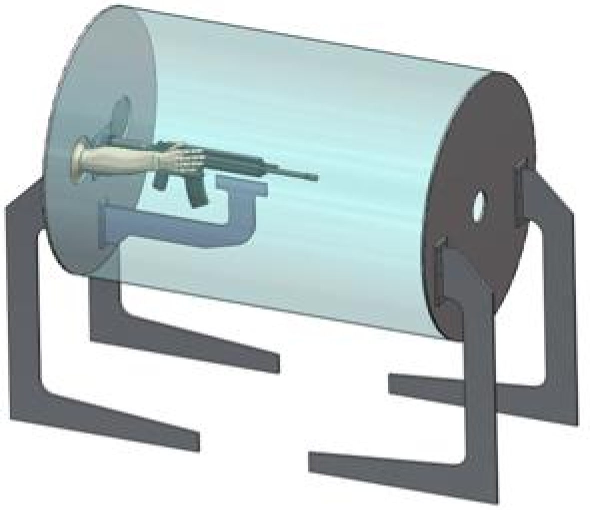


Fig 5.1 Schematic setup of the firing chamber

The forward end plate had an opening in the center which was closed by a sheet of neoprene rubber. The thickness of this sheet was 8 mm. The rubber had the ability to almost close itself after being perforated by projectiles with pointed tips. However, when using bullets with hemispherical tip a 2 – 3 mm large hole was punched out of the rubber sheet. Anyhow, considering the volume of the chamber and the size of the hole, the gas leakage through these holes is considered insignificant as the gas and dust sampling is done a few minutes after the firing.

The plastic sheet that was strapped to the end plates was never as ideal as the figure indicates. The surfaces always got large wrinkles, and the strapping of the sheet was never accurate. Thus the volume of the chamber would have some uncertainty, may be as large as 3 – 4%. This uncertainty is, however, less than the accuracy of the gas and dust measurements.

In each test sequence, ten shots were fired within an interval of 5 – 10 seconds.

After firing, the gas concentration was measured by sucking up an amount of the chamber air. The amount of aerial dust was also found by passing the air through a filter. After that, the plastic sheet was carefully removed and subsequently washed in a bathtub. Thus any dust that had adsorbed to the sheet or had fallen to the bottom of the chamber was accounted for. The washing water had no initial metal content and a small amount of detergent was added in order to make the washing more effective.

The chemical processes of the dust samples are elaborated further in the next section.

Between the firing series, the whole weapon was cleaned with hot water with a small amount of detergent added. Especially the bore and chamber were cleaned very thoroughly. However, certain parts of the reloading mechanism are very difficult to clean completely. Thus, a small degree of contamination may be seen in some firings.

5.2 Chemical analyses

In order to characterize the emission from the weapon, the gases that were anticipated to be the most poisonous ones were selected for measurement. These are carbon monoxide (CO), ammonia (NH_3) and hydrogen cyanide (HCN).

In the following, all concentrations mentioned are values per shot, i.e. the mass of gas emitted by a single shot.

5.2.1 Gas analyses

The concentration of CO, NH_3 and HCN were measured inside the firing chamber. The measurements were regularly done after the first shot, and after all ten shots. The measurements of the gases were done with a Multiwarn II gas sensor produced by Dräger. In this instrument there are three electrochemical sensors that each react to their specific gas. The actual sensors can be replaced according to what gas the user wants to check for. The instrument was coupled to an AirChek XR5000 pump from SKC. This pump sucked up approximately 0.5 liter/minute from the chamber into the Multiwarn sensor.

The Multiwarn sensors have detection limits of 1 ppm (parts per million) for CO and NH_3 and 0.1 ppm for HCN. The instrument has an upper measuring limit of 9900 ppm, 300 ppm and 50 ppm for the gases CO, NH_3 and HCN respectively. For some combinations of ammunition and weapon the concentration after 10 shots could exceed the measuring limit. In those cases the concentration was based on the value measured after one shot or supplementary measurements (see below).

Figure 5.2 shows the measurement setup for analysis of the actual gases for dust sampling. For calibration of the instrument, a gas with a concentration of 250 ppm CO, 100 ppm NH_3 and 10 ppm HCN was used

Supplementary to the Multiwarn II instrument, the concentrations of CO and NH_3 were also measured by Dräger indicator tubes. This was done in order to have a quality check of the Multiwarn measurements, and to get values in those cases were the upper measurement limits for instrument were exceeded. The tube used for CO was CH29901 with a measurement range of 0.3 – 7 percent in volume. For NH_3 the indicator tube CH31901was used with a range of measurement of 0.05 – 1 percent of volume. The amount of sampling was 10 times the volume of the hand pump that goes along with these tubes.

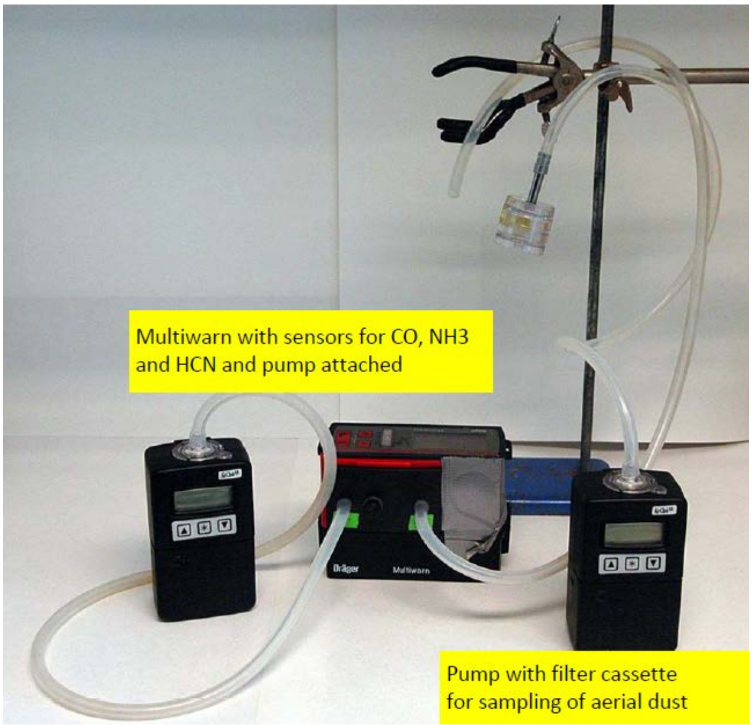


Figure 5.2 Instruments for the analysis of the gases CO, NH_3 og HCN and the filter for dust sampling from the chamber.

5.2.2 Metal analyses

In order to determine the amount of aerial dust emitted and the amount of metal in this dust, air samples from the firing chamber were taken immediately after firing. The air from the chamber passed through an Isopore^{TM} membrane filter of the HTTP Millipore type with a 0.4 µm pore size. The filter was placed in a filter cassette. Air was pumped through the filter with a rate of 2 liters per minute by an AirChek XR5000 pump; the same kind of pump as was used with gas sampling. Before use, the pump rate was checked and adjusted if needed. The sampling lasted for 5 minutes. Thus, the total amount of air that passed through the filter was 10 liters. The filters were weighed before and after use.

After completion of the sampling, they were treated with nitric acid (HNO_3) at 75 ^oC for at least 24 hours in order to determine the amount of metals. The filter was then put into a 100 ml bottle. 20 ml of 65% super pure HNO_3 was added before the bottle was carefully closed. The bottle was then stored for at least 24 hours at 75 ^oC. The treated sample was then diluted to 100 ml with ultrapure water. Before the chemical analyses, the sample was further diluted by a factor of 300 with 1 % HNO_3.

After the sampling of aerial dust, the polyethylene sheet was carefully released from the end plates of the chamber. The inside of the sheet was cleaned in a bathtub and the washing water was collected. For the washing, a garden spray bottle filled with distilled water was used. A few drops of detergent were added to the water. The sheet was then sprayed with water, while the sheet was scrubbed with an ordinary dishwashing scrub in order to get as much as possible of the adsorbed particles. The water used for washing was then collected in a big bottle and filtered through a paper filter of the type Whatman™ no. 3 using vacuum. This filter has a particle retention of 6 μm.

Before further treatment, some filters were photographed under an Axioscop2 microscope fitted with a Zeiss camera. The filter was then transferred to a 100 ml bottle with 40 ml *aqua regia* (a mixture of chloric acid and nitric acid at the ratio of 3 to 1) before carefully closing the bottle. The bottle was then stored for at least 24 hours at 75 ^{o}C. The sample was then diluted to 100 ml with ultra pure water. Before the chemical analysis the sample was then diluted by a factor of 3000 with 1% HNO_3.

From the water left over by the filtering a 100 ml sample was collected. To this sample, nitric acid was added so that the acid concentration was 4%. Before chemical analysis, the samples were diluted by a factor of 100 with HNO_3.

In the chemical analysis the following metals were quantified:

- aluminium (Al)
- antimony (Sb)
- arsenic (As)
- barium (Ba)
- bismuth (Bi)
- cadmium (Cd)
- calcium (Ca)
- copper (Cu)
- cobalt (Co)
- chromium (Cr)
- iron (Fe)
- lead (Pb)
- magnesium (Mg)
- manganese (Mn)
- mercury (Hg)
- nickel (Ni)
- potassium (K)
- sodium (Na)
- strontium (Sr)
- tin (Sn)
- titanium (Ti)
- zink (Zn)

In some samples also molybdenum (Mo) was determined. The content of metals was determined by use of ICP-AES (Inductively Coupled Plasma Atomic Emission Spectrometry), ICP-SFMS (Inductively Coupled Plasma Sector Focusing Mass Spectrometry), or AFS (Atomic Fluorescence Spectrometry) at ALS Laboratory Group (ALS Geochemistry) in Luleå, Sweden.

Figure 5.3 Water collected after cleaning of the polyethylene sheet. The two bottles are from two different ammunitions.

6 Health related norms

It is very difficult to give a clear answer to what is an acceptable concentration of gases and dust in the ambient air. Such a norm will, to a high degree, depend on duration of exposure. In addition, some groups of the population, like children, elderly people, or people with certain medical conditions, may react strongly to an exposure which may not be noticed by the majority of the population

In the US, several institutions have issued values for acceptable concentration of certain chemicals. The values we are concerned with are for inhalation, not for ingestion. These numbers are collected in table 6.1. The institutions referred to are:

- NIOSH - National Institute of Occupational Safety and Health (US Department of Health and Public Services)
- OSHA - Occupational Safety and Health Administration (US Department of Labor)
- ACGIH - American Conference on Governmental Industrial Hygienists (An international organization with headquarter in Cincinnati, Ohio)

It is worth noticing that the element strontium, commonly used in primers and tracers, has no apparent negative health effects. The element is chemically closely related to calcium, and the body tends to react in a similar manner. Popular opinion seems to regard strontium as a hostile element. This is probably due to the fact that a certain strontium isotope is often mentioned as a product of nuclear fission.

Table 6.1 Health related norms for acceptable exposure of different substances.

Component	NIOSH	OSHA	ACGIH	Short term symptoms	Long term symptoms
CO	35 ppm TWA 200 ppm STEL	50 ppm TWA	25 ppm TWA	Heart/lungs	
NH_3	25 ppm TWA 35 ppm STEL	25 ppm PEL	25 ppm TWA 35 ppm STEL	Irritation of eyes and breathing	Eye and throat irritation, breathing problems
HCN	5 ppm STEL	10 ppm TWA	5 ppm STEL	Laxity, headache, nausea	Unknown
H_2S	10 ppm STEL	10 ppm TWA 15 ppm STEL	10 ppm TWA 15 ppm STEL	Eye and throat irritation	Laxity
Pb	0,1 mg/m^3TWA	0.05 mg/m^3 TWA	0.15 mg/m^3 TWA	Kidneys, blood, nerves	
Cu	1 mg/m^3 TWA	1 mg/m^3 TWA	0.2 mg/m^3 TWA	Metal fever	Skin changes
Zn (oxide)	6 mg/m^3 TWA 15 mg/m^3 STEL		5 mg/m^3 TWA 10 mg/m^3 STEL	Metal fever	
Sb	0.5 mg/m^3	0,5 mg/m^3	0.5 mg/m^3	Stomach pains, cough, skin rashes	
Ba	0.5 mg/m^3		0.5 mg/m^3 TWA	Eye, skin and mucosa problems	Hypertension
Bi	n/a	n/a	n/a	Naussea	Gum condition
Sn	2 mg/m^3 TWA	2 mg/m^3 TWA	2 mg/m^3 TWA	Eye and skin irritation	
Ti (oxide)	n/a	15 mg/m^3 TWA	10 mg/m^3		Breathing problems
Mo	10 mg/m^3	15 mg/m^3 TWA	10 mg/m^3		
Sr	n/a	n/a	n/a	No negative effects known	No negative effects known
Hg	0.01mg/m3 TWA 0.03 mg/m3 STEL		0.01mg/m3 TWA 0.03 mg/m3 STEL		

TWA = Time-Weighted Average during 5 days work with 8 hours daily.

STEL = Short Term Exposure Limit

PEL = Permissable Exposure Limit

REL = Recommeded Exposure Limit

7 Measurements

The following presents the main results of the measurements. Elements that were searched for, but not found in any significant amounts, are in general not included.

All the results shown are given in terms of emitted mass per shot. As mentioned earlier, almost all results are thus an average value for 10 individual shots.

The results are arranged and sorted in different ways in order to be able to make sensible comparisons.

It became evident during the work that the great majority of the metal emission in terms of mass was the aerial dust. Thus the values for metal found in the washing water are in general not included here. It is also acknowledged that the metal dust that floats around in the air is a more serious problem than larger particles that quickly falls to the bottom of the firing chamber. Thus, focusing on the aerial dust will probably give the most correct picture of the health related risks.

7.1 Accuracy of measurements

The spectrometric measurement procedures used by ALS in this work are not too accurate. Such inaccuracies are inherent for these kinds of measurements. This is also seen in cases were several measurement have been done on the same combination of weapon and ammunition.

Examples of relative accuracies are

- barium	20%
- copper	20%
- manganese	150%
- lead	20%
- zinc	40%
- antimony	25%
- tin	60%
- bismuth	unknown
- molybdenum	70%

A consequence of this is that only the first digit of the result is significant. In the following tables the results are given mostly in micrograms (μg) and partially in milligrams per shot. The limited accuracy must be taken into account when results are compared.

For the gas measurement, the accuracy seems to be in the order of 20%.

7.2 4.6 mm

This is still not a common caliber, but it is used in the MP-7 personal defence weapon that has been acquired by the Norwegian Army. So far the number of ammunition types available is quite limited. Just one type was tested.

Table 7.1 Gas measurements for the 4.6 mm

Ammo	NH_3 (mg)	HCN (mg)	CO (mg)
BNT 2 HP	236	2.4	0.5

Table 7.2 Aerial dust measurements for 4.6 mm

Ammo	Cu (µg)	Zn (µg)	Bi (µg)	Pb (µg)	Sb (µg)	Ba (µg)	Total (mg)
BNT 2 HP	1080						5

7.3 5.56 mm ammunisjon

This ammunition is the main subject for this study. A wide variety of ammunition and weapons was tested. See chapter 2 and 3 for the description of ammunitions and weapons respectively.

Table 7.3 Tests with HK416N with different ammunitions

Ammo	NH_3 (mg)	HCN (mg)	CO (mg)
NM229	35	6.7	920
B4	15	5.3	1150
M855	28	6.6	759
DT4	28	6.6	805
SS109	33	5.2	702
NM230	29	3.7	575
Frangible (Federal)	28	10.5	851
Frangible (ICC)	15	1.8	713
AP3	11	4.5	564
C77	26	5.4	696
M193	29	7.9	610

Table 7.4 Tests with NM229 and SS109 with different weapons

	SS109 (mg)			NM229 (mg)		
Weapon	NH_3	HCN	CO	NH_3	HCN	CO
HK416N	33	5.2	702	19	3.9	1150
HK416K	26	4.6	592	36	9.9	817
G36	29	9.7	782	36	5.1	598
M16	42	11.9	897	42	8.6	897
AUG	36	9.0	753	37	9.9	955
LMG	32	8.9	949	26	6.1	828
C8 CQB	33	9.5	575	37	8.6	920
C8 SFW	17	5.0	805	25	4.9	805
F2000	40	11.2	690	40	4.9	690

As we can see, there is no significant difference between SS109 and NM229 in terms of gas emission. The observed variations do not exceed the accuracy of measurement. This is not unexpected as both have almost the same amount of propellant and often also the same powder composition.

Table 7.5 Tests with HK416N with different ammunitions

Ammo	Cu (µg)	Zn (µg)	Bi (µg)	Ti (µg)	Pb (µg)	Sb (µg)	Ba (µg)	Total (mg)
NM229	23400	4890	2160	66				41
M855	10530	1500		14	2706	579	219	20
DT4	36900	3810	51	17	993	345	208	55
SS109	8610	1152			1665	336	231	24
NM230	20040	4200	1680	40	74			34
Frangible (Federal)	7950		3540	76			84	22
Frangible (ICC)	18600	2991	61	61				37
AP8	16560		36	12				29
C77	14100	1548	17		2166	711	276	26
M193	7620	678	21		3390	564	215	17

Table 7.6 Tests with NM229 and SS109 with different weapons

Weapon	Ammo	Cu (µg)	Zn (µg)	Bi (µg)	Pb (µg)	Sb (µg)	Ba (µg)	Total (mg)
HK416N	SS109	8610	1152		1665	345	231	24
	NM229	23400	4890	2160				41
HK416K	SS109	8850	996	21	3210	585	564	24
	NM229	18780	4890	3240	150		75	39
G36	SS109	6330	690	56	4170	753	783	22
	NM229	10680	3270	2373	87			27
M16	SS109	3120		73	2340	384	279	19
	NM229	8970	2904	1719	193		76	21
AUG	SS109	3450	792	36	2946	513	405	15
	NM229	14340	3780	2670	312	35	77	30
LMG	SS109	8790	1044	56	2796	546	450	19
	NM229	14040	3060	1827	97		70	26
C8 CQB	SS109	13020	1353	58	3630	666	585	24
	NM229	18420	4590	2643				38
C8 SFW	SS109	8100	936	42	2373	424	312	16
	NM229	18210	4230	2781	390	267	170	36
F2000	SS109	10290	1236	59	3090	609	465	18
	NM229	18210	4410	2895	88	38		36

This test is quite revealing. It is evident that the emission from NM229 is larger than that of SS109 for all weapons. This statement is valid both for copper and zinc. The high concentration of zinc will, to some extent, depend on the use of zinc peroxide in the primer. However, the copper must, for both kinds of bullet, originate from the jacket. Thus, there are good reasons to believe that the difference is due to the composition of the bullet. The NM229 has a core made of steel, while SS109 has one made of lead. Both have a front core made of hardened steel. The NM229 will thus be a far more rigid bullet than SS109. The latter will be able to deform to some extent. Thus, the NM229 will exert a higher pressure against the bore than SS109, and the abrasion of copper from NM229 will therefore be higher.

7.4 Consistency test of 5.56 mm

A number of tests were done in order to check the consistency of the measurements. The weapon used was again HK416N and the ammunitions were NM229 and SS109.

Table 7.7 Gas measurements of two kinds of 5.56 mm ammunition

	NH_3 (mg)	HCN (mg)	CO (mg)
NM229	24	7	614
NM229	40	5	567
NM229	39	10	811
SS109	37	11	655
SS109	53	16	958

Table 7.8 Dust measurements of two kinds of 5.56 mm ammunition

	Cu (μg)	Zn (μg)	Bi (μg)	Pb (μg)	Sb (μg)	Ba (μg)	Total (mg)
NM229	22920	4740	2691	185	121	239	42
NM229	22650	4200	2898				40
NM229	25950	5160	3060				46
SS109	10110	1635	101	2139	405	336	21
SS109	13320	2127	76	2844	531	504	27

As can be seen, the consistency is quite good, but not perfect. This is as expected. The first series of NM229 shows non-zero values for lead, antimony and barium. These are hard to explain, but may be due to contamination of the reloading mechanism of the weapon.

7.5 7.62 mm

The 7.62 mm x 51 has, more or less, the same inventory of ammunition as the 5.56 mm.

The amount of propellant used in 7.62 mm is around 2.75 g compared to 1.65 g for 5.56 mm. In addition 7.62 mm usually has extruded powder while 5.56 mm usually has ball powder. Despite the higher amount of propellant, the amount of poisonous gases emitted by 7.62 mm is about the same as for 5.56 mm. This is somewhat strange as the total amount of gases must be 40% higher in the case of 7.62 mm. Consequently the fraction of the poisonous gases must be less in 7.62 mm. A plausible explanation for this is the difference in composition between ball powder and extruded powder.

Table 7.9 Gas measurements with different ammunitions

Ammo	NH_3 (mg)	HCN (mg)	CO (mg)
NM60	33	7.7	873
NM62	44	5.7	509
NM231	22	2.3	534
NM232	20	1.9	479
AP8	23	3.4	637

Table 7.10 Dust measurements with different ammunitions

Ammo	Cu (µg)	Zn (µg)	Bi (µg)	Pb (µg)	Sb (µg)	Ba (µg)	Total (mg)
NM60	5486	1435		10384	852	417	33
NM62	13697	2128		4036	63	337	38
NM231	9177	4899	2225	100			38
NM232	16698	4726	1987	74	144		44
AP8	4761	1618		4485	1070	383	26

7.6 9 mm

Table 7.11 Gas measurements of 9 mm ammunition

Ammo	NH_3 (mg)	HCN (mg)	CO (mg)
Parabellum GFL	2.9	0.6	64
NM233	0.5	0	53
Frangible	0.8	0.2	40

Table 7.12 Dust measurements of 9 mm ammunition

Ammo	Cu (µg)	Zn (µg)	Bi (µg)	Pb (µg)	Sb (µg)	Ba (µg)	Total (mg)
Parabellum GFL	236	596		5692	618	918	11
NM233	428	2722	509	48			7
Frangible	1096	569					7

The amount of emission is quite low. The emission of lead probably originates from the primer, from an anti-coppering (decoppering) compound in the powder, and from the rear end of the projectile.

Clearly the high zinc emission from NM233 must be caused by the zinc peroxide in the primer.

7.7 Ammunitions where the bullet was interchanged

In an attempt to find trace the source of the emission, some special tests were made in which the bullets of two equivalent, or almost equivalent projectiles, were interchanged. The pairs of projectiles for which this exercise was done, all contained one leaded ammunition and one non-leaded ammunition.

This kind of operation should be done with caution as in all kinds of ammunition there is a subtle balance between the projectile mass, the cartridge volume and the amount and properties of the propellant. Therefore in all the present cases, the amount of propellant had to be adjusted to get the right muzzle velocity. A first order estimate of the adjustments was obtained by interior ballistic calculations, but final adjustments were based on test firings. The table below shows how these adjustments were made.

Table 7.13 Adjustment of the powder content

Ammunition (cartridge)	Original powder mass	Powder mass added(+) or removed(-)
M855	1.641 g	- 99 mg
NM229	1.676 g	+53 mg
NM60	2.759 g	-145 mg
NM231	2.770 g	+64 mg
Parabellum GFL	.395 g	-43 mg
NM233	.380 g	+57 mg

Table 7.14 Gas measurement for ammunitions where the bullets are interchanged

Ammo	NH_3 (mg)	HCN (mg)	CO (mg)
M855 w/NM229 bullet	28	8.6	782
NM229 w/M855 bullet	24	4.3	719
NM231 w/ NM60 bullet	16	1.7	470
NM60 w/NM231 bullet	32	4.8	558
GFL w/NM233 bullet	2.9	0.5	51
NM233 w/GFL bullet	0.4	0	47

Table 7.15 Dust measurement for ammunitions where the bullets are interchanged

Ammo	Cu (μg)	Zn (μg)	Bi (μg)	Pb (μg)	Sb (μg)	Ba (μg)	Total (mg)
M855 w/NM229 bullet	20340	2598	21	1008	480	233	25
NM229 w/M855 bullet	7230	2190	951	1281	44		16
NM231 w/ NM60 bullet	2174	3692	2352	4451	449		33
NM60 w/NM231 bullet	6417	1687	46	3340	61	287	24
GFL w/NM233 bullet	596	509	12	1886	916	1420	9
NM233 w/GFL bullet	320	2745	866	1238			10

These results indicate, when compared with the original ammunition, that the main sources of the metal emission are the bullet and the primer. It is not possible to state that any emission originates from the inside of the cartridge. However, a minor erosion from the inside of the cartridge may be hidden in the variation of the results.

7.8 Other ammunition

7.8.1 Plastic short range

This is a kind of ammunition that is known in Norway as ”blue plastic”. It has a plastic cartridge and a lightweight bullet of the same material. It is made for training purposes as its range is limited to 100 – 150 m. However, the muzzle velocity is very high, usually between 1200 and 1500 m/s.

Table 7.16 Gas measurement of ammunition with plastic bullet

Ammo	NH_3 (mg)	HCN (mg)	CO (mg)
NM250	2.3	0.3	215

Table 7.17 Dust measurement of ammunition with plastic bullet

Ammo	Cu (µg)	Zn (µg)	Bi (µg)	Ti (µg)	Sr (µg)	Total (mg)
NM250		1347	22	132	56	5

7.8.2 Blank ammunition

This type of ammunition is known in Norway as ”red plastic”. It is a blank ammunition without any projectile. The cartridge is made of red colored polyethylene and contains a primer and a small amount of powder.

Table 7.18 Gas measurement of blank ammunition

Ammo	NH_3 (mg)	HCN (mg)	CO (mg)
NM226F1	2	0.9	239

Table 7.19 Dust measurement of blank ammunition

Ammo	Cu (µg)	Bi (µg)	Pb (µg)	Sn (µg)	Ba (µg)	Ti (µg)	Total (mg)
NM226F1		366	1239	2616	747	105	3

The cartridge contains 0.43 g of extruded powder.

7.8.3 7.62 mm x 39

This test was a bit beside the main objective of the study and was made somewhat out of curiosity. The ammunition used was a standard cartridge for the AK-47 Kalashnikov gun, which is the main small arm in a large number of nations.

As can be seen from the results the aerial dust contains quite high amounts of antimony which is probably due to the use of antimony sulfide in the primer. This compound is often used together with mercury fulminate and potassium chlorate. Mercury is thus also found in the aerial dust. The gas measurement, however, did not show any high concentrations of poisonous gases.

Table 7.20 Gases from AK-47

Masses in mg	NH_3	HCN	CO
M43 – test 1	10	2.0	543
M43 – test 2	10	1.4	411

Table 7.21 Aerial dust from AK-47

Masses in µg	Cu	Pb	Sb	Hg	Sn	Ti
M43 – test 1	6930	282	2397	248	159	11
M43 – test 2	7980	369	2742	369	153	17

8 Emission sources

It seems evident that there are 4 sources for metal dust during firing. These are

1. the primer
2. the jacket
3. additives in the powder
4. the rear end of the projectile (e.g. where the core is exposed)

8.1 Sources of zinc

Zinc is an especially interesting material. It is supposed to be the only material, beside copper, of those observed here, that may cause metal fever. Zinc may have three sources:

- the primer (zinc peroxide)
- the projectile (the jacket)
- the cartridge (as an alloy element in brass, but this is not a likely source)

The jacket is copper alloyed with some zinc in the ratio 9 : 1. If the jacket were the only source, we should measure the same ratio in the emission.

In the table below, we have differentiated between ammunition with and without zinc in the primer. Standard guns, i e HK416N and AG-3 has been used if not otherwise mentioned.

For the 5,56 mm, table 8.1 indicates that the non-leaded types, beside DT4, contain relatively more zinc than lead based on the alloy composition of the jacket, which is zinc / lead in the ratio of 1 : 9. However, as the table shows, the ratio is around 1 : 4.5, which indicates that about half of the zinc content originates from the primer. The rest comes from the jacket. From the non-leaded ammunition the lead content is around 4 mg per shot. The amount of zinc from the primer is thus around 2 mg per shot.

Table 8.1 Ratios between copper and zinc in the aerial dust.
**) There is an additional source of copper in the tracer cover plate*
#) Average of 8 different weapons (not HK416N)
¤) Ammunition with exchanged bullet

Ammo with zinc in primer	Zinc in aerial dust (mg)	Cu : Zn ratio in aerial dust	Ammo without zinc in primer	Zinc aerial dust (mg)	Cu : Zn ratio in aerial dust
NM229	4.89	4.8	M855	1.5	7.0
DT4*	3.81	9.7*	SS109	1.15	7.5
NM230	4.2	4.8	C77	1.6	9.1
NM229#	3.8	4.0	M193	0.7	11.2
			SS109#	0.88	8.7
NM229¤	2.2	3.3	M855¤	2.6	7.8
NM231	3.7	0.6	NM60¤	1.7	3.8
NM232	4.7	3.5	NM60	1.4	3.8
NM231	4.9	1.9	NM62	2.1	6.4

8.2 Abrasion of the jacket

The jacket interacts with the bore (i e the inner surface of the barrel) as it travels down the barrel. The surface of the jacket undergoes both some degree of elastic-plastic deformation and some degree of abrasion. One can distinguish between three separate processes.

1. Engraving of the jacket as the beginning of the lands of the rifling cuts into the jacket. This is both an abrasive process and a process of plastic deformation, but careful observation of the mass of the projectile before and after firing indicates that it is mainly an abrasive process.
2. Friction between the jacket and the bore caused by the fact that the cross section of the projectile is larger than the bore cross section. Therefore, both the jacket and the core of the projectile are subject to an elastic deformation, and maybe even a plastic deformation, to fit into the bore. The friction force will be highly dependent on the elastic properties of the projectile materials.
3. Friction between the jacket and the bore caused by inertial setback forces that try to contract the projectile axially and expand it in the radial direction. During the first stage of the projectile travel, where the acceleration is high, this contribution is significant, but it is mainly independent of the materials present in the projectile.

8.3 The profile of the bore.

According to most STANAGs the bore of small arms should have a constant diameter, and the caliber is defined at the bore diameter measured between the tops of opposite lands. However, the bore is not always made this way. In many cases, the gun manufacturer does different tricks to improve the accuracy of the weapon. One of those tricks is to make the bore slightly conical by letting the diameter decrease slowly from the chamber to the muzzle. With such a bore the projectile must progressively deform.

Careful measurements of the bore profile showed that there was a significant difference between bores that were all nominally 5.56 mm. There were quite large variations between the different manufacturers, and there was also some variation between bore made for the same gun by the same manufacturer.

When comparing the measurements of metal emission with the diameter of the bore, it appears to be a negative correlation between those two parameters. A narrow bore gives high emission.

It is also evident that it would not be useful to compare just the average diameter of the bore with the emission. The emission would probably be different in a bore that is narrow near the chamber and wide at the muzzle, and vice versa. We have therefore used an ad hoc parameter that accounts for this. We have called this parameter the *constriction index*, I_C, and it is defined as:

$$I_C = \frac{1}{2V_b} \int_{bore} \left(\frac{dA}{dx} \right) \left(\left| \frac{dA}{dx} \right| - \frac{dA}{dx} \right) dx$$

The integrand accounts for the change in diameter down the bore. *A* is the bore cross section. The integration is made along the projectile travel. V_0 is the volume of the bore section. The constriction index will be highest for the narrowest bores. It will be high for those bores where the cross section narrows evenly. Finally the, the apparently awkward definition has the consequence that the sections where the cross section increases do not contribute.

A bore with a constant diameter and a standard bore diameter will have a constriction index equal to zero.

When the aerial dust emission is plotted against the constriction index, there is a clear indication of increasing emission with increasing index for the steel-cored NM229 bullet. However for the lead cored SS109, no such correlation is apparent.

The figure 8.1 also shows one outlier, which is the value for NM229 fired by the M16 rifle. We do not have a good explanation for this.

It must be said that the choice of constriction index is a matter of discussion. There are many ways of defining such an index. However, the present one tries to catch the important factors related to abrasion of the jacket.

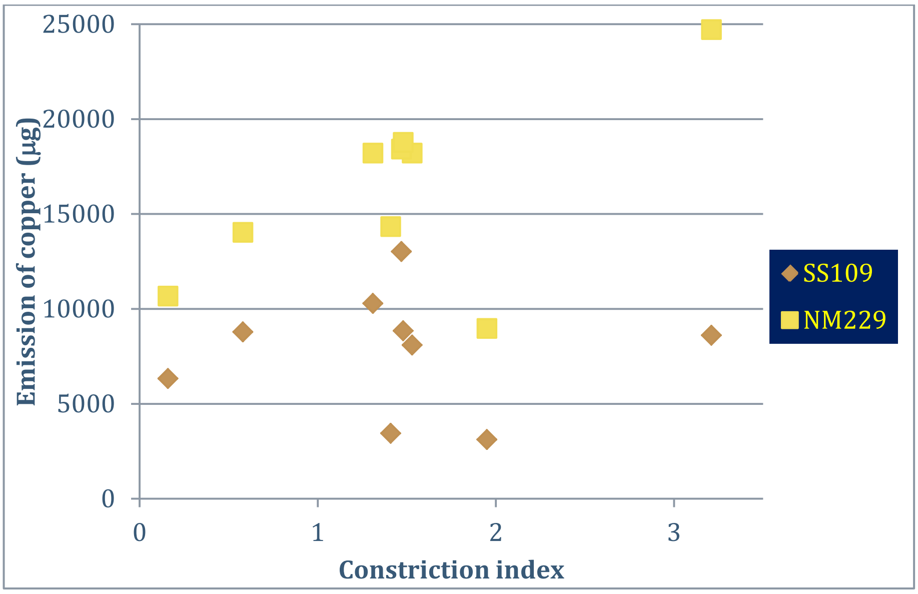


Fig 8.1 Emission vs constriction index for different weapons.

9 Conclusion

The purpose of the measurements presented herein has been to find the causes for the health related problems by the users of certain small arms ammunition.

Measurements have been made with a large number of combinations of weapons and ammunitions. Measurements of certain gases in the combustion products, and metallic dust that mostly originates from the surface of the projectile, have been made.

The following conclusions may be drawn:

- A substantial amount of metallic dust is emitted from the weapon. Typically 10 – 20 mg of copper and zinc are found as aerial dust.
- The metallic emission is larger for bullets with a steel core than for bullets with a soft lead core
- The amount of emission also has a weapon component as some weapons regularly emit more dust than others.
- There is a quite clear and positive correlation between metallic emission and the narrowness of the bore when the bullet has a hard core
- Bullets with a soft core do not show any correlation between the metal emission and the narrowness of the bore.
- A significant amount of metallic dust may originate in the primer. This is especially the case for primers containing zinc peroxide.

The abrasion process on the surface of the bullets is not yet fully understood.