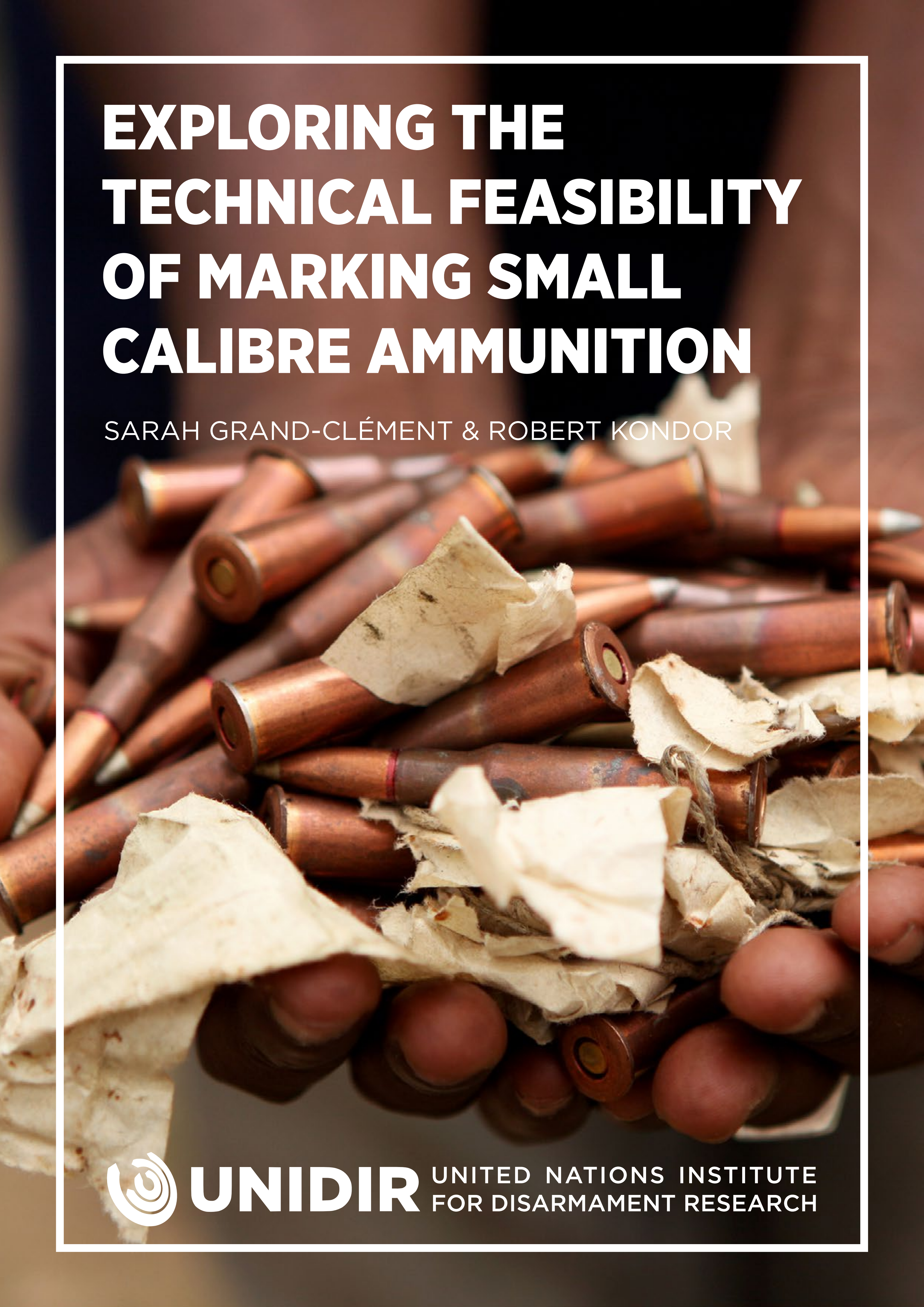
EXPLORING THE TECHNICAL FEASIBILITY OF MARKING SMALL CALIBRE AMMUNITION

SARAH GRAND-CLÉMENT & ROBERT KONDOR



UNIDIR UNITED NATIONS INSTITUTE FOR DISARMAMENT RESEARCH

ABOUT UNIDIR

The United Nations Institute for Disarmament Research (UNIDIR)—an autonomous institute within the United Nations—conducts research on disarmament and security. UNIDIR is based in Geneva, Switzerland, the centre for bilateral and multilateral disarmament and non-proliferation negotiations, and home of the Conference on Disarmament. The Institute explores current issues pertaining to a variety of existing and future armaments, as well as global diplomacy and local tensions and conflicts. Working with researchers, diplomats, government officials, NGOs and other institutions since 1980, UNIDIR acts as a bridge between the research community and Governments. UNIDIR activities are funded by contributions from Governments and donor foundations.

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NOTE

TABLE OF CONTENTS

ABOUT UNIDIR ii

ACKNOWLEDGEMENTS ii

REFERENCE ii

NOTE ii

ABOUT THE AUTHORS iv

ABOUT THE RESEARCH TEAM v

SUMMARY 1

KEY TERMS 3

1. INTRODUCTION 4

2. AMMUNITION MARKING METHODS 8

- **2.1 STAMPING** 8
  - 2.1.1 THE MARKING AND THE METHOD 8
  - 2.1.2 COSTS 9
  - 2.1.3 ASSESSMENT 9
- **2.2 LASER MARKING** 10
  - 2.2.1 THE MARKING AND THE METHOD 10
  - 2.2.2 COSTS 12
  - 2.2.3 ASSESSMENT 13
- **2.3 CHEMICAL TAGGANTS** 14
  - 2.3.1 THE MARKING AND THE METHOD 14
  - 2.3.2 COSTS 15
  - 2.3.3 ASSESSMENT 15

3. CONCLUSION 17

REFERENCE LIST 21

APPENDIX: RESEARCH INTERVIEWS 23

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UNOCI CONDUCTS DISARMAMENT OPERATION IN ABIDJAN

An ex-combatant holds up munitions in Attécoubé, Abidjan, Côte d'Ivoire. He is one of several to have participated in a Disarmament, Demobilization and Reintegration (DDR) operation conducted in the area by the UN mission, UNOCI.

UN Photo. Abidjan, Côte d'Ivoire.
www.unmultimedia.org/photo

SUMMARY

While ammunition packaging sometimes contains information on the ammunition, such as the manufacturer, the customer, the specific lot number, the year and location of production and more, individual rounds of small calibre ammunition usually contain only a fraction of this information. This means that, once rounds are unpacked and distributed, specific details that could enable the identification and tracing of individual ammunition rounds are lost.

Marking individual rounds of small calibre ammunition with sufficient relevant information such as the calibre, manufacturer, importing country, year of manufacture and specific lot or batch number, alongside accurate and long-term record-keeping, can help improve identification and tracing of recovered rounds and help identify any point of diversion, as such markings can aid criminal investigations of armed violence or help determine the efficacy of arms embargoes, ultimately reducing the loss of human lives.

This report explores three different marking technologies: stamping, laser marking and chemical taggants. The aim is to demonstrate which methods are available to mark small calibre ammunition rounds with sufficient identifying information to enable identification, profiling, and tracing. This research aims to inform the ammunition processes taking place under the auspices of the United Nations, such as the upcoming Open-Ended Working Group on Conventional Ammunition, and aid in the implementation of the outcomes of such processes. It also aims to inform national mechanisms and legislation on the importance and feasibility of ammunition marking.

A comparative overview of these different marking methods is provided in the table. It should also be noted that these different markings can be combined and used altogether on a single round. Double or triple marking can therefore help overcome challenges faced by individual methods.

Comparison of the marking methods

	Stamping	Laser marking	Chemical taggants
Durability and recoverability of the marking	Durable and recoverable	Durable and recoverable	Testing indicates durability but data regarding long-term use remains limited
Equipment and process[1]	Equipment and processes are for the most part already in place given that stamping is the traditional and most common marking method	Equipment and processes are in place in selected factories or companies which have specifically chosen to use this method	Equipment and processes remain limited in scope as this method is in a pilot stage
Volume of information included in the marking	Depending on the information to be included, space may be limited	Substantial amounts of information can be included	Substantial amounts of information can be included
Ability to mark across the life cycle of a round	Only at the early production phase of a round	At various stages of the production process and post-production depending on the location of the marking[2]	Can be applied at any point in the production process including post-production, but is easier to achieve at the production stage

Based on these findings, it can be concluded that:

- While each marking method comes with its own sets of advantages and challenges, the marking of small calibre ammunition rounds with sufficiently detailed information to facilitate profiling and tracing and prevent and combat diversion is technically feasible. In addition, associated costs are also not off-putting given that some of the countries that have currently introduced or are seeking ammunition marking are lower-income countries.
- Agreement in standardized minimum information requirements for ammunition rounds is required in order to offset the fact that there is currently no universal standard stating which information small calibre ammunition should be marked with.
- Legislators and policymakers play a key role in demanding that small-calibre ammunition be marked and with what information and ensure that industry follows suit.
- Costs of ammunition marking are context specific and are influenced by a number of factors including the re-designing the manufacturing process, training needs, the production rate and volume, the size of lots to be marked, decisions such as whether or not to mark individual rounds with a unique identifier, and specific record-keeping requirements.
- Data collection and record-keeping of ammunition markings are crucial regardless of the marking methods used, as these data can help with the tracing and identification of the ammunition.

1 This refers to the equipment required to undertake the marking and the extent to which the method is incorporated into the production/post-production process, not the ease of applicability of the method.

2 More efficient for large volumes of rounds when integrated in the production or post-production process before packaging.

KEY TERMS

This report focused on small arms ammunition, otherwise known as small calibre ammunition. The definition of small calibre ammunition follows that of UNIDIR's *Handbook Profiling Small Arms Ammunition in Armed Violence Settings*: "those rounds designed to be fired through firearms with rifled barrels up to a bore diameter of 14.5 mm and cartridges designed for use in smooth bore weapons up to 10 gauge (19.7 mm)".[3] The types of weapon that fire small calibre ammunition include revolvers andself-loading pistols; sub-machine guns; shotguns; rifles, assault rifles, and carbines; light, medium and heavy machine guns; and anti-materiel rifles.

3 Malaret Baldo & Martinez Miralles (2020, 17).

1. INTRODUCTION

Due to their availability and ease of use, small arms play an instrumental role in "shaping the onset, severity and duration" of armed violence and armed conflict.[4] Their use causes death or injury to thousands of people worldwide every year.[5] They also have detrimental secondary impacts including the suppression of human rights, development and economic growth, in addition to putting women and girls at increased risk of gender-based and sexual violence.[6] Ammunition is intrinsically tied to the use of small arms and their impacts. As noted by the International Action Network on Small Arms (IANSA): "ammunition transforms [small arms and light weapons] from inoperative objects into lethal weapons that can be used to take away human lives and devastate communities".[7]

As demonstrated by UNIDIR's Diversion Analysis Framework, small calibre ammunition runs the risk of being diverted at various junctures during its lifetime, which is compounded by its long shelf life.[8] Recent research has highlighted the longevity of ammunition: of a dataset of over 800 rounds with a known date of manufacture, "the average age of the cartridges.... is 33 years".[9] In particular, once rounds are unpacked and distributed, specific details regarding these rounds are lost.[10] Diversion can result in ammunition being used by unauthorizedusers, such as criminal groups, insurgent and terrorist forces, and other non-state armed groups.[11] Additionally, authorised users, including civilians, can use ammunition for illegal or criminal purposes. Marking of ammunition and/or its packaging is one approach which, when employed in conjunction with accurate record-keeping, can help trace points of diversion and identify recovered rounds to help with criminal investigations or to determine the efficacy of arms embargoes.

Discussion Box 1. The potential issue of reloaded ammunition

Reloaded ammunition refers to use of cases from expended rounds to create new ammunition. There are concerns that the reloading of ammunition, and in particular ammunition with a unique identifier, could mislead tracing efforts and incriminate a customer that is not responsible for diversion to an illicit end user.[12] While it is important to be aware of this potential issue, available evidence suggests that a very small amount of diverted ammunition is usually found to be reloaded.[13] Most importantly, forensic experts can identify reloaded ammunition.[14] Therefore, the practice of reloading ammunition does not represent a significant reason for not marking small calibre ammunition.

4 General Assembly (2009, 8).
5 UN News (2020).
6 OECD (2005).
7 IANSA (2021, 1).
8 A. Malaret et al. (2021, 6).
9 Desmarais et al. (2022).
10 Interviews with experts C, I, J and M.
11 UNODA (2021).
12 Interviews with expert A; Persi Paoli (2011).
13 Interview with expert A.
14 Interview with expert K.

While the purpose of this report is not to outline what specific information should be included in the markings, these data are nonetheless of particular importance. Yet, there is a lack of international standards on the marking standards of small calibre ammunition rounds for tracing and security purposes. Minimum recommended information varies (see box 2), although relevant information would, for example, include the calibre, manufacturer, importing country, year of manufacture, and specific lot or batch number (i.e., unique identifiers). Year of manufacture is of particular interest as, beyond its value for tracing purposes, it can also better help understand "how rapidly ammunition can be diverted for illicit use after it is manufactured".[15]

Discussion Box 2. Guidance regarding the information contained in ammunition markings

There have been several multilateral efforts to provide guidance on the information to include in ammunition marking. The International Ammunition Technical Guidelines (IATG) notably provides guidance on the information the markings should contain as well as where they should be applied. This includes both the ammunition packaging and the individual rounds. However, these guidelines are voluntary and primarily relate to the marking of ammunition packaging as opposed to the marking of individual rounds.

The Organization for Security and Co-operation in Europe (OSCE) *Handbook of Best Practices on Conventional Ammunition* provides guidance regarding the marking, registration and record-keeping of ammunition. It also covers stockpile management and security and the transportation and destruction of ammunition. As with the IATG however, this guidance is voluntary.

The North Atlantic Treaty Organization (NATO) also provides a set of ammunition standards that describe how ammunition and their packaging produced by NATO member states should be marked. However, these standardization agreements (STANAGs) only call for the inclusion of a limited set of information that was originally designed to respond to safety issues related to larger calibre ammunition.

The United Nations Regional Centre for Peace, Disarmament and Development in Latin America and the Caribbean (UNLIREC) proposes in its T*echnical Guide for the Marking of Small Arms and their Ammunition* the information to include in the markings, with a focus on security of ammunition.[16] The proposed information to be included is shown below.

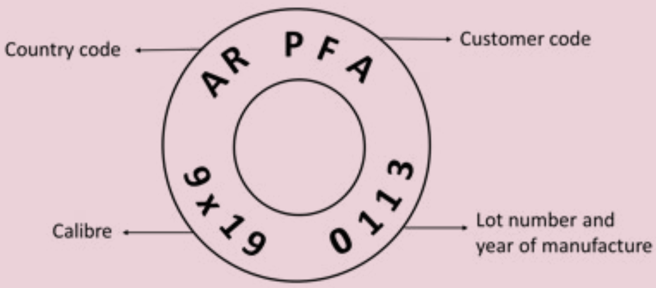


Image credit: UNLIREC

15 Desmarais et al. (2022).
16 UNLIREC (2013).

While there is no international requirement or universal marking standard, there have been ongoing United Nations-level discussions on improving the safety and security of ammunition, such as within the Group of Governmental Experts (GGE) on Problems Arising from the Accumulation of Conventional Ammunition Stockpiles in Surplus, and forthcoming discussions within the 2022 Open-Ended Working Group (OEWG) on Conventional Ammunition. Progress is also being made at the national level, with the driver often being violent crime and a desire to understand the origin of the ammunition used.[17] As noted in the GGE's 2021 report: "A select number of States have adopted requirements or practices of applying lot and batch numbers to individual small-calibre cartridges for specific procurements at the request of certain end users, with the aim of identifying, dissuading and combating diversion when deemed feasible, practicable and consistent with national legislation".[18] These countries include Brazil, the Dominican Republic, Jamaica, Madagascar and Peru. The case of Brazil is described in further detail in box 3.

Discussion Box 3. Ammunition marking as a requirement: the case of Brazil

Under Brazil's Federal Law No. 10,826 of 2003, which came into force in 2005, the packaging of all types of ammunition must have a barcode to "enable the identification of the manufacturer and the purchaser". It also requires that the ammunition itself must be marked if it is for use by law enforcement authorities and military forces specifically.[19] Regarding the ammunition for use by law enforcement authorities and military forces, the legislation specifically states that the lot and the acquirer need to be placed on the shell of the projectile, although it does not stipulate the marking method to be used. The legislation also specifies that each lot must contain no more than 10,000 rounds.[20] However, there have been calls to reduce the number of rounds to 1,000 per batch in order to improve tracing and identification of ammunition.[21] This legislation also requires information-transfer procedures and record-keeping, with data to be kept for 20 years.[22]

The technical details of this legislation had been discussed beforehand between the government and industry – specifically the only small calibre ammunition manufacturer in Brazil, which continues to maintain a monopoly on the internal Brazilian market following this legislation.

Since this legislation entered into force, the head of the ammunition case is stamped with details of the year of manufacture and manufacturer at the start of the manufacturing process and then a unique identifier is engraved in the extractor grove via laser marking at the end of the production line before packaging.[23] The inclusion of markings has enabled the tracing and identification of diversion points, which has fed into criminal investigations. However, such investigations have also shown when the terms of the legislation have not been abided by. Notably, examination of the ammunition used in the murder of Marielle Franco, a member of the Rio de Janeiro council, in 2018 showed that it was part of a batch of over 1.8 million rounds – several orders of magnitude beyond the 10,000 round maximum specified in the legislation.[24]

17 Interviews with experts H, P, Q, S.
18 General Assembly (2021, 21).
19 Interviews with experts H and P.
20 Ministério da Justiça e Segurança Pública (2021); Interview with expert K.
21 Interview with expert F.
22 Martinez Miralles & Mack (2018); Interview expert F.
23 Martinot & Berkol (2008).
24 Langeani & Pollachi (2021).

Based on data obtained from 17 interviews with 20 experts from research organisations, industry and the military (see the list in the appendix) as well as desk-based research, this report explores three different methods for marking small calibre ammunition: stamping, laser marking and chemical taggants. The aim of this paper is to demonstrate which methods are available to mark individual ammunition rounds with sufficient information to enable identification, profiling, and tracing. The research aims to inform the ammunition processes taking place under the auspices of the United Nations, such as the upcoming OEWG, and aid in the implementation of the outcomes of such processes. It also aims to inform national mechanisms and legislations on the importance and feasibility of ammunition marking.

For each method – stamping, laser marking and chemical taggants – the type of marking, its method and associated costs are described. There is then a discussion of the advantages and challenges regarding the durability and recoverability of the marking; the equipment and process for marking ammunition; costs; the volume of information included in the marking; and the ability to mark across the life cycle of a round.

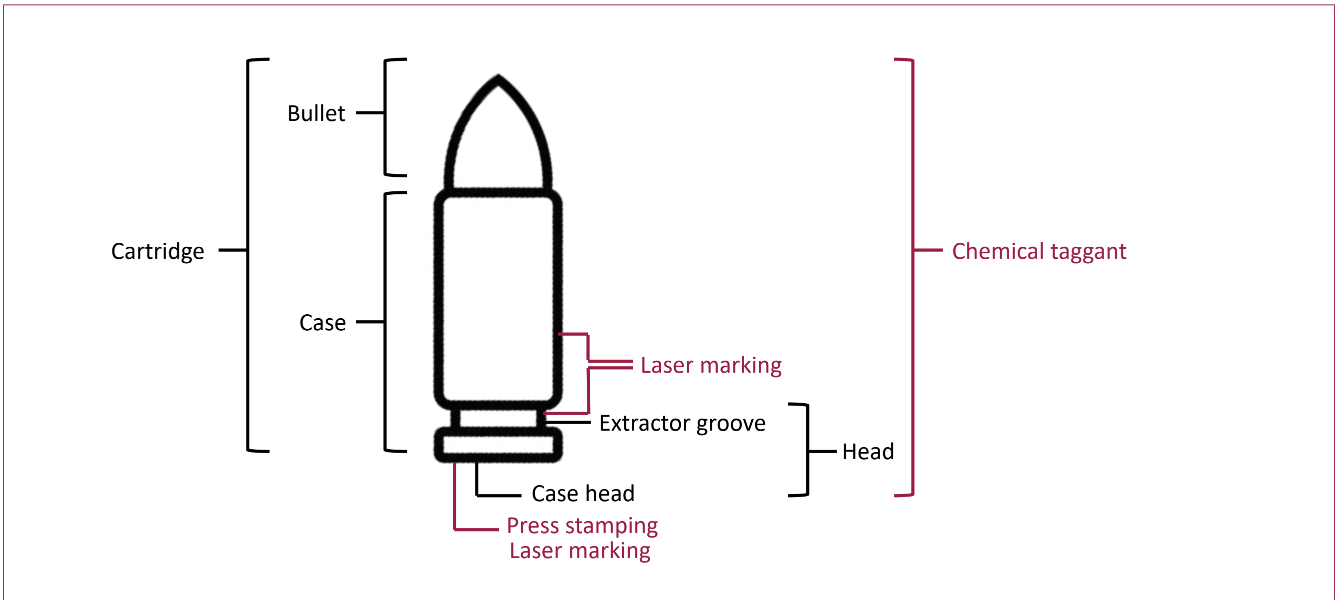
2. AMMUNITION MARKING METHODS

2.1 STAMPING

2.1.1 The marking and the method

Stamping of small calibre ammunition, also known as "headstamping", is the most common method for applying marks directly to individual rounds.[25] This method marks through deformation of the cartridge case. There are two methods for stamping: press stamping, by first applying pressure to create the mark with a single stamp; or roll marking, where the stamp head gradually moves or rolls across the surface. Press stamping usually applies to the head of the case, whereas roll marking is applied to the side.[26] The marking provided by stamping is visible and is usually placed on the case head of the casing for small calibre ammunition, as this is the place on the cartridge where the metal is thickest (see figure 1).[27] The marking is usually applied during the manufacturing process on empty cartridges.

Figure 1. Anatomy of a round and the possible placements of different marking methods



Following Brazil's 2003 legislation (see box 3), the small calibre ammunition manufacturer in Brazil explored the possibility of including the lot number information within the headstamp in addition to the other information already part of the headstamp markings. However, it found that the case head offers only a small area to stamp. In addition, once the round is complete this area is sensitive to stamp since it includes the primers. Therefore, the manufacturer chose to add the lot number using laser marking instead of headstamping,[28] with the rest of the information still added via headstamping.

25 Interviews with experts I and M.
26 Persi Paoli (2011).
27 Persi Paoli (2013); Interview with expert N.
28 Interview with expert E.

Despite this one example, it is nonetheless possible to add relevant and detailed information via headstamping: figure 2 illustrates different types of headstamped ammunition, with the images on the left featuring how multiple types of information – such as country code, importer code and calibre – could be added, as is the case for ammunition marked in the Dominican Republic, as opposed to the more limited data on the ammunition on the image on the right.

Figure 2. Examples of headstamped ammunition[29]

Image credit: UNLIREC

2.1.2 Costs

Stamping appears to be the most cost-effective technique for marking individual rounds, as it is commonly an integrated step in the manufacturing process of ammunition.[30] For that same reason, it is hard to disaggregate the actual costs of this marking method. However, general costs for this method include the costs of the machinery and their maintenance and the costs of individual head stamps (bunters). Costs will potentially increase depending on whether individualized markings are required, as production must be paused to enable the change of bunters.

2.1.3 Assessment

Table 1 provides an overview of the advantages and challenges of stamping.

29 In this example, the code "RD" stands for República Dominicana.

30 Interviews with experts I and M.

Table 1. Advantages and challenges of stamping

Advantages	Challenges
• **Durability and recoverability of the marking.** Headstamps are durable in the long term.[31] For example, headstamps on cartridges as old as 80 years, and even over 100 years, have been found to still be readable.[32]	• **Cost.** The use of unique identifying information on smaller-sized lots could lead to an increase in costs.[34] However, it is difficult to quantify how that may differ from other methods as it depends on factors such as the number of individualised headstamps required and how frequently these would require to be changed, which has an impact on the rapidity of the production process.
• **Equipment and process.** Most ammunition producers already possess headstamping machines and undertake this type of marking as part of their production and branding process (although with variations in terms of the information included).[33]	• **Volume of information included in the marking.** There may not be sufficient space on the case head to stamp all the information to be included in the marking, particularly for smaller calibres.[35] However, this depends on the amount and type of information to be included.
	• **Ability to mark across the life cycle of a round.** Stamping can only be applied early in the production phase of a round; retroactive stamping of live ammunition is not possible. This could have an impact on the current manufacturing process, where cartridges are produced before knowing who the specific end client will be. Thus, applying unique identifiers could require an adaptation to the current manufacturing process, which could be mitigated by producing smaller lot sizes per customer.[36]

2.2 LASER MARKING

2.2.1 The marking and the method

Laser marking – also called laser engraving – applies a visible mark directly on individual rounds. This method applies marks via the removal of material, as opposed to its deformation. This marking method can be applied at the end of the production process to completed or live ammunition, meaning that it can be used retrospectively.[37] However, the location of the marking affects when the marking is applied during the process. For example, marking in the extractor groove means that the marking can be applied at the end of the manufacturing process, prior to being packaged and sent to the customer.[38] Marking other areas, such as the side of the cartridge or its case head, means that the marking is usually done before the primer is added for safety reasons.

31 Desmarais et al. (2022); Florquin & Leff (2014).
32 Zaili et al. (2007).
33 Interviews with experts I and M.
34 Anders (2006).
35 Interviews with experts E and O.
36 An important nuance to note here is lot by customer and lot by materials used to manufacture a round are two different pieces of data. This for example means that two separate customers can have two different lot numbers by customer (secondary lot mark), but have the same lot number by materials (primary lot mark), indicating what propellant, primer and more has been used in these specific rounds.
37 Martinez Miralles & Mack (2018).
38 BICC (n.d.).

The type of marking and where it is placed varies depending on the manufacturer. Alpha-numeric characters are one option. These can be placed in the extractor groove twice (see figure 3) or on the side (see figure 4) or even the case head of a cartridge.[39] The rationale for such locations is that the engraving is not affected when used in firearms.[40] In particular, marking in the extractor groove, an area made of solid metal where the laser engraving can be relatively deep, can help prevent the removal of the marking.[41] However, marking on the side of the case offers a larger marking area, and can be a helpful alternative when there is no extractor groove.

Figure 3. Example of a cartridge with a laser marking in the extractor groove (from Brazil)

Photo credit: Rosilene Miliotti

Figure 4. Example of laser marking on the side of a cartridge (from Madagascar)

Photo credit: Carlos Martínez / Couth

39 Interviews with experts L and N.
40 Martinot & Berkol (2008).
41 Persi Paoli (2011); Martinot & Berkol (2008).

Codes, such as barcodes or data matrix codes are another option (see figure 5). This can enable the inclusion of detailed information, such as the manufacturer and the lot and batch numbers, using a limited amount of space. A smartphone application can then be used to scan the code, with the amount of information provided through the application depending on the permissions assigned to the user.[42]

Figure 5. Example of laser marking using a data matrix code

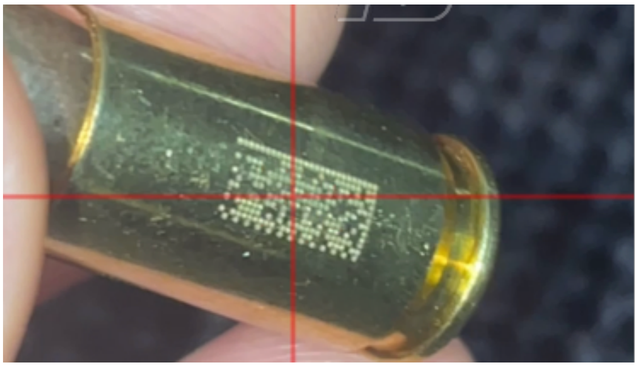


Photo credit: The Bullet ID Corporation

Laser marking is very rapid; cartridges can be marked in the space of several seconds.[43] However, the exact speed depends on the type of laser and the type and location of the marking: the type of laser and its wattage will affect the amount of ammunition that can be engraved at once. For example, a bigger lens and a machine with a higher wattage will be able to engrave a larger number of cartridges faster. The location and type of marking also affects the speed of the process; thicker symbols take longer, as do areas where the marking needs to or can be deeper – such as on the case head of the cartridge.[44]

2.2.2 Costs

The costs of laser marking include the costs of the laser-marking machine and its maintenance. In the case of Madagascar, four laser-marking machines were purchased for US$95,190 in 2019.[45] This included the provision of training to the manufacturing personnel. However, costs will differ depending on the type of technology and machine purchased. In the case of Brazil, the local manufacturer reportedly purchased laser-marking machines for approximately $100,000 per unit including record-keeping costs, with maintenance costs estimated at $9,300 per 5 million cartridges.[46] Other costs include the additional time necessary to mark ammunition. Costs can also vary depending on the size of the production run, with the production of a higher number of rounds decreasing the production costs compared to smaller numbers of rounds.[47]

An alternative laser-marking business model includes the provision of the laser machinery and the tracking and stockpile-management software to the manufacturer at no cost. Instead, the cost is based on the total production amount, with the marking and recording of that data in the software charged for each individual round. For example, one company provides these two services at $0.02 for each round.[48]

42 Interviews with experts Q and S.
43 Interviews with experts Q and S.
44 Interview with expert N.
45 ATT (2021).
46 Martinez Miralles & Mack (2018).
47 Interview with expert F.
48 Interviews with experts Q and S.

2.2.3 Assessment

Table 2 provides an overview of the advantages and challenges of laser marking.

Table 2 Advantages and challenges of laser marking

Advantages	Challenges
• **Durability and recoverability of the marking.** Over time, laser marking could cause secondary damage to ammunition via corrosion, particularly in areas with high humidity. However, this can be avoided, especially if a coating is applied after the marking process. Furthermore, while it is possible to remove laser markings, especially marks that have little depth,[49] it is generally unlikely that this would be attempted given the time required to remove such markings from individual rounds.[50] The removal of markings can also be made more difficult if a coating is applied over them.[51] If they are nonetheless removed, obliterated markings can be recovered via "relief polishing and reflected light stereomicroscopy."[52]	• **Equipment and process.** Laser marking of unique identifiers involves similar challenges to stamping in terms of the trade-offs between the timing of the marking, knowing the end-users and the size of orders, and the current manufacturing process.[54] In addition, most ammunition producers do not have laser-marking machines and would need to acquire and integrate them into their processes. This would also include establishing new security directives and norms to account for laser machinery.
• **Volume of information included in the marking.** Laser marking is well adapted to enable the marking of small areas with a substantial amount of information.	• **Costs.** Costs of laser marking are hard to quantify as these will differ based on factors such as location and type of marking, as well as volume and speed of production. There are two additional overarching cost factors for consideration: the machinery is not yet in widespread use and an initial investment is therefore necessary;[55] and, for a large majority of manufacturers, laser marking would require an adaptation to the manufacturing process.
• **Ability to mark across the life cycle of a round.** This marking can be applied to various areas of the cartridge and, depending on the area, at various stages of the production process. This means that laser marking can adapt to different manufacturing processes and thus be integrated at a stage most suitable for the manufacturer. This also means that this method can be used to mark ammunition retrospectively, with a unique identifier added post-production.[53]	

49 Interviews with experts A, K and N.
50 Interviews with experts H and P.
51 Interview with expert N.
52 Da Silva & dos Santos (2008).
53 Anders (2006).
54 Interview with expert M.
55 Interview with expert L.

2.3 CHEMICAL TAGGANTS

2.3.1 The marking and the method

Chemical taggants are invisible additives which can be used to mark a range of objects. There is one known example of its use on ammunition: a commercial solution, AmTag, developed by two private sector companies (a policy research organisation and a technology provider), is currently being piloted in Burkina Faso and Mali, where it is applied to loose ammunition held by police or military forces.[56] As the pilot is still ongoing, there are no results yet on the added value of this method.

This marking can be applied directly onto individual rounds of ammunition as well as to the ammunition packaging.[57] AmTag is comprised of "inorganic, water-based traceable liquids [that] are colorless, chemically-coded solutions".[58] AmTag's fluorescent particles are only visible under an ultraviolet (UV) light (see figure 6). The taggant is not DNA-based, so "will withstand fire, humidity and sunlight".[59] Each AmTag batch has an individual chemical composition that is linked to a unique code, which is registered once the specific batch is used and includes information such as the manufacturer and year of production. When the code is entered into a proprietary software application, it is linked with information on when the taggant was applied.[60]

Figure 6. Example of ammunition with AmTag under UV light

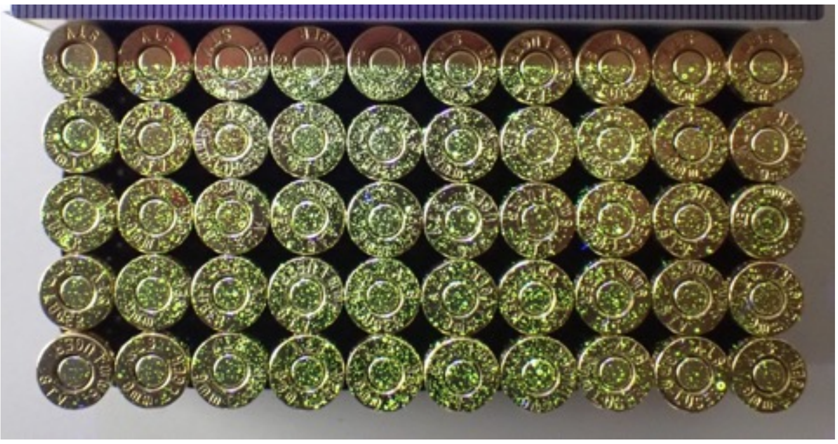


Image credit: Jonathan Rickell / Conflict Armament Research

AmTag is applied via an atomising spray to the surface of the headstamp and cartridge case. This can be done during the ammunition manufacturing process or retrospectively. The solution can be applied to all types of ammunition, regardless of age, condition or calibre. The solution could also be applied at the end of the ammunition-manufacturing process to associate ammunition with an end user or unique identifier.[61]

Based on data from the pilot, the solution takes under 30 minutes to dry, although it is only chemically stable after 24 hours, during which time there is a small possibility of transfer of the product to the skin or other surfaces with which it may come into contact. AmTag can sometimes transfer from the ammunition to the weapon, but this does not impair the functionality of either the ammunition or the weapon. Furthermore, according to data from the pilot project, tests have not found the solution to be toxic. In order to investigate recovered

56 Interview with expert D.
57 Interview with expert M.
58 SmartWater (n.d.).
59 SmartWater (n.d.).
60 Interview with expert M; Evans (2012).
61 Interview with expert M.

ammunition, residue of the solution needs to be extracted and sent for analysis. Currently, there are analysis centres in France, the United Kingdom and the United States.[62]

2.3.2 Costs

The costs of using the AmTag chemical taggant include purchasing the solution and its code, which is called a "profile license". The current solution, which is being developed as a feasibility study and limited-scope pilot programme, costs $20–55 for 15 millilitres, while the license, which is granted for five years, costs approximately $1,900. Given the novelty of this solution, it remains to be determined how much ammunition this volume of AmTag is able to mark.[63]

Should ammunition be sent for testing after expiry of the profile license, the license will be renewed automatically. This means that an ongoing profile license is not needed for the entire life cycle of the ammunition. Given that this marking can be applied after the manufacturing process is complete and therefore does not change or impact the process, there may be minimal cost implications to the production rate.[64]

2.3.3 Assessment

Table 3 provides an overview of the known and potential advantages and challenges of chemical taggants, with a focus on AmTag since it is the only known chemical taggant applicable to ammunition. However, it should be noted that there is limited information about this technology beyond the current pilot project as it has not yet been implemented in industrial production processes, and this is an overall challenge regarding the assessment of this method.

Table 3. Advantages and challenges of AmTag

Advantages	Challenges
• **Durability and recoverability of the marking.** Testing during the AmTag pilot project suggests that the chemical taggant could remain on ammunition for long periods of time, perhaps decades. However, there is insufficient data on the long-term use of the solution, especially in different environments and after use.	• **Equipment and process.** The time taken for the solution to dry on the ammunition can be seen as lengthy, depending on when in the process the solution is applied. Furthermore, there are currently analysis centres in only three countries, with none in the Global South. As a relatively little-known and non-visible method, forensic or ballistic experts may not realise that ammunition is marked or may not have the necessary equipment to identify the marking. At this stage in its development, the technology thus remains exclusive to a limited number of users.
• **Volume of information included in the marking.** Given that the data is stored on database linked via a code to the solution, detailed information about the ammunition can be stored.	• **Costs.** There is too little information on the costs related to this method to offer an assessment at this stage.
• **Ability to mark across the life cycle of a round.** This solution can be applied to the entire round of ammunition at any point in the production and post-production process.	

62 Interview with expert M.
63 Based on correspondence with expert N in October 2021 and March 2022.
64 Interview with expert M.

Beyond these three methods, radio-frequency identification (RFID) tags could potentially provide another solution. This currently remains hypothetical, as discussed in box 4.

Box 4. Can RFID tags be integrated into ammunition?

RFID is a technology which serves to track items by way of a tag placed on or attached to each item. RFID technology is comprised of a chip, an antenna attached to the chip and an external reader. Data are encoded in the chip, transmitted via the antenna and read by the reader. RFID tags are used on certain ammunition packaging as well as light weapons, and there is some debate as to whether RFID tags could be integrated directly onto or into the ammunition itself. This type of marking has been used for ammunition over 20 millimetres.[65] In the case of small calibre ammunition, opinions from interviewees differ, with some believing that it is not a viable solution.[66] One interviewee opined that it is possible, so long as the tag is not applied on electrically ignited ammunition.[67]

One interviewee also stated that it would theoretically be possible to insert a very small (2 mm or under) passive RFID tag operating at extremely high frequencies (3–60 gigahertz) in an individual round. This tag would have a very short read range of several millimetres. To ensure that the tag can still be read, it should not be enclosed completely in metal, as metal hampers radio waves. A suggested solution is to cover the tag with an epoxy resin.[68] It should, however, be noted that the functionality of such an approach has never been tested. Interestingly, this idea is not recent, as a patent application from 2006 proposes mounting RFID tags within individual (civilian) rounds, claiming that the tag did not affect the performance.[69] Yet, in addition to the feasibility of adding this technology to individual rounds, there are also further unanswered questions, in particular regarding the costs and desirability of such an approach.

65 Interviews with expert C.
66 Interviews with expert A.
67 Interview with expert B.
68 Interview with expert R.
69 Pridmore JR & Babendreier (2006).

3. CONCLUSION

Marking individual small calibre ammunition rounds can help trace points of diversion and identify recovered rounds in order to understand the contextual factors around their use. However, there is a lack of sufficient information on individual rounds themselves to enable their tracing and identification. This is compounded by the lack of international standards and norms on this matter, although there are voluntary guidance documents. Despite this gap, there are mature and emerging methods available to mark ammunition with a range of information, including substantial amounts of unique identifying information. As new techniques and approaches continue to be developed, and existing ones refined, this report aims to start a dialogue regarding the possible next steps in the marking of small calibre ammunition for increased security purposes.

A comparative overview of the three marking methods examined in this paper is provided in table 4. It should also be noted that these different marking methods can be combined and used altogether on a single round. Double or triple marking can therefore help overcome challenges faced by individual methods.

Table 4. Comparison of the ammunition marking technologies

	Stamping	Laser marking	Chemical taggants
Durability and recoverability of the marking	Durable and recoverable	Durable and recoverable	Testing indicates durability but data regarding long-term use remains limited
Equipment and process[70]	Equipment and processes are for the most part already in place given that stamping is the traditional and most common marking method	Equipment and processes are in place in selected factories or companies which have specifically chosen to use this method	Equipment and processes remain limited in scope as this method is in a pilot stage
Volume of information included in the marking	Depending on the information to be included, space may be limited	Substantial amounts of information can be included	Substantial amounts of information can be included
Ability to mark across the life cycle of a round	Only at the early production phase of a round	At various stages of the production process and post-production depending on the location of the marking[71]	Can be applied at any point in the production process including post-production, but is easier to achieve at the production stage

70 This refers to the equipment required to undertake the marking and the extent to which the method is incorporated into the production/post-production process, not the ease of applicability of the method.

71 More efficient for large volumes of rounds when integrated in the production or post-production process before packaging.

Overall, five main conclusions can be made regarding ammunition marking methods.

Marking rounds to aid tracing is feasible. The marking of small calibre ammunition with sufficiently detailed information to facilitate profiling and tracing and prevent and combat diversion is feasible and it is currently being done in certain contexts as described above. Over the past two decades, a number of manufacturers have modified their marking practices to apply lot and batch numbers to individual small calibre rounds to comply with national legislation or to respond to specific needs at the request of certain end users.[72] This practice has led to successful tracing of small calibre ammunition and to an increase of actionable information generated by ammunition recoveries. Information that could be included in each round for this purpose includes the calibre, manufacturer, specific lot number, year and location of production, end user, and other relevant information. Each marking method comes with its own sets of advantages and challenges, such as the ease of embedding a selected method in the manufacturing process. Associated costs are also not off-putting, given that some of the countries that have introduced or are currently seeking ammunition marking are lower-income countries. End-users and lawmakers who need or decide to require lot or batch markings for security purposes to small calibre ammunition can therefore choose from several marking methods and technologies available in the market. Industry thus plays an important role in ensuring that demand and client needs are met.

The setting of standardised minimum information requirements for ammunition rounds is required. As noted in the introduction, there is currently no universal standard stating which information small calibre ammunition should be marked with. The information contained on ammunition currently varies depending on the buyer and manufacturer, in addition to the fact that rounds can lack unique identifying information – in particular, data such as the year of manufacture and the customer. Yet, as demonstrated by this study, the technology exists to enable the marking of this type of information, even on small calibre ammunition where space is more limited. National governments and subregional, regional and international entities all have a role to play in terms of improving the streamlining of markings in order to enable improved marking. Furthermore, any agreement on such standardised minimum information should also ensure that the data are easily decipherable and understandable by the variety of actors handling ammunition, including recovered rounds.

Legislators and policymakers play a key role in the marking of ammunition. Ultimately, although industry also has a responsibility to offer options to increase the security of small calibre ammunition, the power lies with legislators and policymakers to demand that ammunition be marked, and with what information. These demands vary across contexts, with certain states deeming the marking of ammunition a greater need than others. This also includes a responsibility to ensure that lot sizes are not too large and that lots are not split between different customers, so that tracing efforts are not hampered. Should legislators and policymakers make this demand, manufacturers and users will adapt their processes, as shown by the Brazilian and Dominican Republic examples. However, in such cases it is also important that legislators and policymakers take into account the marking of ammunition destined for both the civilian market and state security forces, given that the large majority of small calibre ammunition is destined for the civilian market. Marking ammunition destined for both markets could help improve tracing, identify points of diversion and ultimately save lives. While the marking of individual rounds

72 See General Assembly (2021).

does come with additional costs attached, which will be reflected in an increase in the price of ammunition, this can be justified in terms of increased transparency, tracing capability, accountability and security, and reduced risk of diversion. Furthermore, the costs linked to the loss of human life remain much higher than the slight cost increase of marking ammunition.

Costs are context specific. While delving into the specific costs of these marking approaches is beyond the scope of this initial exploratory report, it is still an important consideration should laser or chemical marking be brought into wider use. Costs depend on a number of factors such as the cost of new equipment and its related components; the way that manufacturers structure and schedule their production; ongoing costs such as maintenance, which will also be affected by the production rate and volume; training needs; the size of the lots to be marked; and decisions such as whether or not to mark individual rounds with a unique identifier, such as a lot number, and how many rounds should be included within a lot. Larger lots may lower costs, but smaller lot sizes will help ammunition tracing and identifying the point of any diversion. There will also be costs related to the possible need to adapt the way in which ammunition is manufactured – especially if unique identifiers can only be added once an order arrives. Beyond marking, there are other costs to consider regarding record-keeping and communications technology between the manufacturers and the users: What type of information is required to be recorded, and for how long? What security features will be required to ensure that this information is secure? Costs will also vary according to the answers to these questions and may have an impact on political will to mark individual rounds – despite the benefits outlined above. Industry, lawmakers, policymakers and end-users should continue exploring the integration of new marking technologies and enable greater sharing of relevant information, including on costs, between stakeholders.

Data collection and record-keeping on ammunition marking data is important to aid with tracing and identification. Data collection and record-keeping is intrinsically tied to the marking of individual rounds of ammunition with unique identifiers, as it can provide the necessary supporting information to aid the tracing of ammunition recovered in areas of conflict, crime or terrorist activity and can notably help identify diversion points. The selection of a marking technique needs to be done alongside the establishment of a robust, secure and long-term record-keeping system. While research on the requirements of such a system, its cost and its role in the tracing of ammunition were not within the scope of this study, given its importance to ammunition marking it should be the object of further research, particularly to understand how such a system could be developed for ammunition destined for both the civilian market and for state security forces.

MONUSCO CONDUCTS TRAINING ON CLOSE PROTECTION TACTICTS

Ammunition sits in the foreground as peace-keepers from the UN Organization Stabilization Mission in the Democratic Republic of the Congo (MONUSCO) receive firearms training on providing close protection techniques.

Credit: UN photo/Abel Kavanagh

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APPENDIX: RESEARCH INTERVIEWS

We are grateful to the following experts who took part in the research interviews and for the information they contributed.

Designation	Name	Affiliation	Region	Interview date
A	Anonymous expert	–	Western Europe and others (WEO)	14 January 2022
B	Independent ammunition expert	–	WEO	20 January 2022
C	Anonymous expert	–	WEO	24 January 2022
D	Anonymous expert	–	WEO	28 January 2022
E	Anonymous expert	–	Latin America and the Caribbean	8 February 2022
F	Anonymous expert	–	Latin America and the Caribbean	11 February 2022
G	Anonymous expert	–	WEO	25 February 2022
H	Anonymous expert	–	Latin America and the Caribbean	25 February 2022
I	Rodolfo Gamboa	Independent expert	Latin America and the Caribbean	6 January 2022
J	Stefan Feller	German Federal Foreign Office	WEO	8 February 2022
K	Marcus Vinicius Da Silva Dantas	Brazilian Federal Police	Latin America and the Caribbean	31 January 2022
L	Gen. Emma Randri-amiaramanana	Madagascan Ministry of Defence	Africa	4 February 2022
M	Jonathan Rickell	Conflict Armament Research	WEO	14 February 2022

APPENDIX: RESEARCH INTERVIEWS

Designation	Name	Affiliation	Region	Interview date
N	Carlos Martinez	Couth	WEO	28 February 2022
O	Karl Weiss	United States Army Combat Capabilities Development Command Armaments Center	WEO	24 February 2022
P	Natalia Pollachi	Sou da Paz	Latin America and the Caribbean	25 February 2022
Q	Bruce Lewis	Bullet ID Corporation	WEO	7 March 2022
R	Andreas Weder	Fraunhofer	WEO	28 February 2022
S	Cristian Talle	Bullet ID Corporation	WEO	7 March 2022

EXPLORING THE TECHNICAL FEASIBILITY OF MARKING SMALL CALIBRE AMMUNITION

Marking individual rounds of small calibre ammunition with sufficient relevant information such as the calibre, manufacturer, importing country, year of manufacture and specific lot or batch number, alongside accurate and long-term record-keeping, can help improve identification and tracing of recovered rounds and help identify any point of diversion, as such markings can aid criminal investigations of armed violence or help determine the efficacy of arms embargoes, ultimately reducing the loss of human lives. This report explores three different marking technologies: stamping, laser marking and chemical taggants. The aim is to demonstrate which methods are available to mark small calibre ammunition rounds with sufficient identifying information to enable identification, profiling, and tracing. This research aims to inform the ammunition processes taking place under the auspices of the United Nations, such as the upcoming Open-Ended Working Group on Conventional Ammunition, and aid in the implementation of the outcomes of such processes. It also aims to inform national mechanisms and legislation on the importance and feasibility of ammunition marking.

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