Blunt Impact Safety Evaluation of Less-Lethal Impact Munitions

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Preface

This report provides the background and context of a blunt force trauma assessment methodology for less-lethal kinetic energy impact munitions. The NATO STANREC 4744, Standard AEP-99, is considered to be the preeminent thoracic impact test method to evaluate blunt force trauma and is discussed with reference to its basis, safety inferences, and relation to the current state-of-science for injury assessment.

The report is intended to accompany the test methodology and evaluation programs conducted by Biokinetics for less-lethal kinetic energy munitions. A summary of thoracic blunt impact injury risk with the KWESST and AR40-1 munition is provided and accompanies the corresponding test report (Biokinetics' Test Report: TR2430 KWESST, July 19, 2024).

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Table of Contents

List of Figures

List of Tables

Glossary

Acronym	Description
AEP	Allied Engineering Publications
AIS	Abbreviated Injury Scale
ASTM	American Society for Testing and Materials
BTTR	Blunt Trauma Torso Rig
NLKE	Non-Lethal Kinetic Energy
NSO	NATO Standardization Office
STANREC	Standardization Recommendation
VC	Viscous Criterion

1. Overview

This report is intended to provide a basis of the test methodologies used in assessing potential injuries from less-lethal kinetic energy impact munitions. Reference to published information from the standards groups and the scientific literature are provided summarizing the scientific basis for decisions, interpretations, and implementation of the methodologies for less-lethal munitions.

Guidance and context is usually required in the interpretation of injury risk evaluations as not all injury mechanisms, modes, severities, threat types, impact velocities and subject anatomical, age, and sex differences have been fully characterized to represent the range of possible outcomes. As such, most current test methods highlight the conditions under which they were derived so that validity can be better assessed. For example, while the STANREC AEP-99 standard for thoracic blunt trauma has been based on a wide range of threats, biomechanical test conditions and threat types, there have been advances with munition designs that may fall outside the studied threat velocities or energies. The scientific experts will, therefore, note these limitations to make the reader aware of these when interpreting their data. It also helps to identify areas of future research that are required to complete our understanding of injury outcomes.

The report starts with a brief introduction of impact munitions, their intended function, potential injury risks and external factors that affect their end effectiveness. This is followed by a summary of standard test methods, their methodology and limitations when evaluating injury risks. Finally, a summary of the current test results is presented in the context of the background materials.

2. What are Less-Lethal Impact Munitions

Less-lethal impact munitions are used by law enforcement and corrections agencies to carry out a number of functions including, but not limited to, dispersing/controlling unruly crowds, dissuading individuals from further aggression through incapacitation, and to ensure continued safety of the officers or general public. Less lethal weapons are integral to the use-of-force continuum[1] in the military peacekeeping role and law enforcement community where non-lethal options are desired before escalating to lethal options. The intended consequences of less lethal weapon use is that any adverse effect or injury sustained by individuals are fully reversible with low risk of permanent injury or loss-of-life [Koene, 2008].

A survey of law enforcement agencies confirmed the operational effectiveness of less lethal impact munitions with over 90% of encounters being resolved without the use of lethal force but some injuries resulted ranging from minor to fatal [NIJ 2004]. While the details of the weapon, conditions of use, injury outcome and victim characteristics were documented, additional details of the event and continuing surveillance by agencies is required to better understand the in-field consequences of this type of deterrent. However, a full understanding can only be realized when complimented with the scientific study of munition interactions, injury modes, human tolerances and influencing factors (e.g. age, sex, anthropometry, clothing).

The terms non-lethal, less-lethal, and less-than-lethal have been used interchangeably to describe impact munitions, and while intended to confer that they are not lethal, the terms carry different connotations. Non-lethal weapons are intended to minimize the likelihood of causing a fatality or permanent injury, whereas less-lethal or less-than-lethal weapons acknowledge that while they are designed to be less harmful than conventional weapons, they still carry a risk of serious injury or death. The distinction reflects an understanding of the inherent risks associated with the use-of-force continuum. The military may prefer the term "non-lethal" to emphasize the intent to avoid casualties, while law enforcement agencies might use "less-lethal" to acknowledge the potential for unintended harm, which also reflects the realities of a society where the consequences of weapon use are closely scrutinized. This terminology is important in the context of rules of engagement and the use-of-force, as it guides both the strategy and the ethical considerations of employing such weapons in various situations.

Among non-lethal weapons, impact munitions, also known as Non-Lethal Kinetic Energy Weapons (NLKEW), have evolved over the years as law enforcement agencies, military and industry gained experience with their use and effectiveness. A brief summary of impact munition types is presented in the continuum of contemporary less lethal weapons by Bunker (1999) and within the fielded and developmental weapons in the Non-lethal Weapons Reference Book (2011) as well as other public sources[2]. Current commercial impact munitions come in various

[1] https://nij.ojp.gov/topics/articles/use-force-continuum
[2] Wikipedia, Non-lethal Weapon, https://en.wikipedia.org/wiki/Non-lethal_weapon.

forms including single or multiple rubber balls, baton rounds, frangible capsules, fin stabilized projectiles, bean bags, and 40 mm diameter "sponge" rounds, some of which are depicted in Figure 1. The deformable nature and shape/size of some impact faces help reduce the potential for injury along with the control of impact speed as affected by the munition charge, launcher characteristics and weapon-to-target/standoff distances.

Figure 1: Sample of impact munitions.

The choice of impact munition is typically chosen by the governing agency with consideration of numerous factors including: operating environment and threats, deterrent effectiveness, targeting accuracy, injury risk, training needs, launcher requirements, availability, costs, field experience, risk acceptance level, policy, strategic, social, political, ethical and legal factors.

3. Injuries from Impact Munitions

The study of injuries from impact munitions is relatively new and the cause and effect is not fully known, however, insight can be gained from the studies collected to date. For example, a study conducted by the National Institute of Justice, documented 969 shots with impact munitions that were collected across 106 law enforcement agencies in the US [NIJ 2004]. Out of these, there were 373 incidents of injury reported with eight fatalities. Five of the fatalities were attributed to chest impacts at standoffs of <10 m (30 ft) and typically involved rib fractures with subsequent lung/heart penetrations. The type of impact munition used primarily included bean bags (65%) and plastic batons (28%) with subjects ranging in age from 18-68 years, mostly males. The impact sites in general comprised the abdomen (34%), chest (19%), legs (15%), arms (14%), back (11%), head (2%), and neck or groin (1%). Furthermore, there were 782 injuries documented consisting of bruises (51%), abrasions (31%), serious lacerations (5.5%), fractures (3.5%), and skin penetrations (1.8%).

While the above study is not definitive, it highlights that many body regions are impacted with the majority to the core and that more vulnerable impacts to the head or neck were relatively infrequent. With the impact locations depending partly on the weapon's accuracy and biases introduced by training and operational protocols it can also be noted that these differences may lead to varying injury severity depending on the specific tolerance of the body region being struck. The scientific literature has noted differences in injury modes and tolerances to the skeleton (ribs, sternum), soft tissue (abdominal), and underlying critical organs (heart, lungs). Although many studies address ballistic behind armour blunt trauma (BABT) effects, it has been suggested that the injurious effects are similar to blunt trauma resulting from direct impact of less-lethal munitions. Needless-to-say, the similarities to less-lethal munition strikes (e.g. energy transfer, impact speed, load distribution) have to be critically evaluated. Alternatively, injury data or blunt trauma studies involving direct strikes from batons and other less-lethal munitions have started to provide greater insight into the risks and severity of injures from less-lethal munitions [Olsen 2020]. In both cases, as a broader knowledge base is gained accounting for subject differences (age, sex, anthropometry) and across the range of munitions, our understanding of injury risks and tolerances will further guide their development and guidelines for use. For now, it is important to be aware of the limitations to not overgeneralize observations or recommendations.

Additional consideration of the standoff distance and impact speed is important to establish safe operating guidelines. This was supported by the above NIJ study where impacts under 3 m (10 ft) were often associated with bone fractures or fatalities. Operationally, controlling standoff distance through rules-of-engagement seem straight forward but the exact critical safe distance will be dependent on the munition's speed, mass, compliance and shape resulting in unique guidelines for each weapon/munition combination. The subject characteristics, social, political and agency factors will also affect the guidelines and, hence, injury risks, as mentioned previously.

4. Operational Considerations of Less-lethal Munitions

Impact munitions or non-lethal kinetic energy weapons are devices that use physical force to incapacitate or deter a target without causing fatal injuries. Impact munitions can be used by law enforcement agencies to control riots, disperse crowds, or subdue violent suspects. However, they also pose significant risks of injury, trauma, and misuse. Therefore, law enforcement officers receive proper training and guidelines to ensure safe and effective deployment of impact munitions.

The burden of ensuring safety of the impact munitions is shared between the manufacturers to provide safe designs and the users who have a responsibility ethical and safe use. To this end, today's law-enforcement officers are highly trained professionals who follow the best practices for training and deployment of less-lethal weapons.

Training in the use of non-lethal weapons is a crucial aspect of law enforcement and security personnel preparation. Here is a typical outline of what such training involves:

1. **Familiarization**: Officers are introduced to various types of less-lethal weapons, including tasers, pepper spray, batons, rubber bullets, bean bag rounds, and conducted energy devices (CEDs). They learn about the mechanics, capabilities, and limitations of each weapon.
2. **Legal and Policy Considerations**: Training emphasizes the legal and policy frameworks governing the use of less-lethal weapons. This includes understanding when it is appropriate to deploy these weapons, the level of force permitted in different situations, and the potential legal consequences of misuse.
3. **Safety Protocols**: Officers are trained in safety protocols to minimize the risk of injury to themselves, their colleagues, and the public when handling and deploying less-lethal weapons. This includes proper handling techniques, storage procedures, and guidelines for assessing the environment before deploying a weapon.
4. **Effective Deployment**: Officers learn techniques for effectively deploying less-lethal weapons in various scenarios. This involves understanding the range, accuracy, and impact of each weapon, as well as tactics for gaining compliance from subjects.
5. **Decision-Making Skills**: Training focuses on developing officers' decision-making skills to assess threats and determine the appropriate level of force needed in a given situation. This includes evaluating factors such as the severity of the threat, the presence of bystanders, and the subject's behavior.
6. **De-escalation Strategies**: While less-lethal weapons are designed to minimize harm, officers are trained to prioritize de-escalation whenever possible. They learn verbal communication techniques and strategies for defusing tense situations without resorting to force.
7. **Scenario-Based Training**: Officers undergo realistic scenario-based training exercises that simulate potential use-of-force situations. This

hands-on training allows officers to practice deploying less-lethal weapons in a controlled environment and receive feedback on their performance.

8. **Aftercare and Reporting**: Following the use of a less-lethal weapon, officers are trained to provide immediate aftercare to any injured parties and to report the incident according to departmental protocols. This includes documenting the circumstances leading up to the use of force and any injuries sustained.
9. **Continuing Education**: Less-lethal weapons training is an ongoing process, with officers receiving regular refresher courses and updates on new techniques, equipment, and legal developments.

By providing comprehensive training in the use of less-lethal weapons, law enforcement and security personnel can effectively mitigate threats while minimizing the risk of serious injury or loss-of-life.

When using less-lethal force, law enforcement and security personnel are trained to target specific areas of the body to minimize the risk of serious injury while still achieving their goal of subduing a subject. These target zones are chosen based on the principle of causing temporary incapacitation or pain without causing lasting harm. Here are some common nonlethal target zones:

1. **Lower Body**: Targeting the legs or feet can help incapacitate a subject by restricting their movement without causing serious injury. Strikes or shots to the legs can disrupt balance and make it difficult for the subject to flee or continue aggressive behavior.
2. **Torso (Non-Vital Areas)**: Strikes or shots to the torso can be effective in causing pain or discomfort without posing a significant risk of serious injury. However, it's crucial to avoid targeting vital organs or areas where the risk of injury is higher.
3. **Upper Arms**: Targeting the upper arms can impair the subject's ability to use weapons or resist arrest without causing significant harm. Strikes or shots to this area can temporarily weaken the subject's ability to move or manipulate objects.
4. **Shoulders**: Striking or targeting the shoulders can disrupt the subject's balance and mobility without causing lasting harm. This can be particularly useful in preventing the subject from using their arms effectively.
5. **Buttocks**: In some cases, targeting the buttocks with less-lethal rounds (such as bean bag rounds) can be effective in causing pain or discomfort without causing serious injury. However, this should be done with caution to avoid causing unnecessary harm.
6. **Muscle Groups**: Targeting large muscle groups, such as the quadriceps or deltoids, can be effective in causing temporary incapacitation without causing significant injury. Strikes or pressure point techniques applied to these areas can help control the subject's movement.
7. **Sensitive Areas (With Caution)**: While targeting sensitive areas such as the groin, eyes, or throat may be effective in rapidly incapacitating a subject, it should be done with extreme caution due to the increased risk of causing serious injury. These areas are generally considered as a last resort or in situations where there is an imminent threat of serious harm to officers or bystanders.

It's essential for law enforcement and security personnel to receive comprehensive training in less-lethal force techniques, including target selection, to ensure they can effectively subdue subjects while minimizing the risk of causing unnecessary harm. Additionally, officers should always prioritize de-escalation and use less-lethal force only when necessary and proportionate to the threat posed.

Police use-of-force guidelines typically outline the principles, procedures, and limitations governing when and how law enforcement officers are authorized to use force in the performance of their duties. These guidelines are designed to ensure that force is used only when necessary and in a manner that is proportional to the threat encountered. While specific guidelines may vary between jurisdictions and law enforcement agencies, they often include the following components:

1. **Use-of-Force Continuum**: Many agencies employ a use-of-force continuum, which outlines a series of progressively more intense actions that an officer may take in response to escalating levels of resistance or aggression from a subject. This continuum typically begins with officer presence and verbal commands, followed by empty-hand control techniques, intermediate weapons such as batons or tasers, and finally, lethal force as a last resort.
2. **Imminent Threat**: Officers are generally authorized to use force only in situations where there is an imminent threat of harm to themselves, other individuals, or the public. The level of force used should be reasonable and necessary to neutralize the threat.
3. **Proportionality**: The amount of force used should be proportionate to the level of resistance or threat encountered. Officers are trained to use only the amount of force necessary to achieve their lawful objectives and to discontinue the use of force once the threat has been neutralized.
4. **Objectively Reasonable Standard**: The use of force is evaluated based on an objectively reasonable standard, considering the facts and circumstances known to the officer at the time of the incident. This standard takes into account factors such as the severity of the alleged offense, the level of resistance or aggression exhibited by the subject, and the availability of other options for resolving the situation.
5. **Verbal Warnings and Commands**: Officers are generally required to issue verbal warnings and commands before using force whenever possible. This provides subjects with an opportunity to comply with lawful orders and can help to de-escalate potentially volatile situations.
6. **De-escalation**: Officers are trained to use de-escalation techniques and tactics to reduce the likelihood of force being necessary. This may involve active listening, empathy, and attempts to establish rapport with individuals in crisis.
7. **Reporting and Documentation**: Any use of force by an officer must be promptly and accurately documented in accordance with departmental policies and procedures. This typically includes completing a use of force report detailing the circumstances of the incident, the level of force used, and any injuries sustained by the subject or officers involved.
8. **Training and Supervision**: Officers receive regular training in the use of force and are supervised to ensure compliance with departmental policies

and procedures. Supervisors play a critical role in reviewing use of force incidents, providing feedback and guidance to officers, and identifying any training needs or areas for improvement.

9. **Accountability and Review**: Use of force incidents are subject to review by internal affairs departments, oversight boards, or other independent bodies to ensure compliance with policies and procedures. Officers who misuse force may be subject to disciplinary action, including termination or criminal prosecution, depending on the severity of the misconduct.

Overall, police use of force guidelines are intended to balance the need for officers to protect themselves and others with the fundamental principles of respect for human rights and the rule of law. By providing clear standards and expectations for officers, these guidelines help to promote accountability, transparency, and public trust in law enforcement agencies.

5. Safety Evaluation of Non-lethal Kinetic Energy Impact Munitions

Less-lethal impact munitions may be used to control threatening crowds or individuals in advance of using lethal force. Evaluation of their safety must be consider their intended performance to immobilize subjects, the operating conditions under which they are used, and the regulatory and procedural requirements stipulated by the organization responsible for their implementation.

For non-lethal kinetic energy (NLKE) impact munitions, their operational effectiveness is dependent on several factors including those in Figure 2.

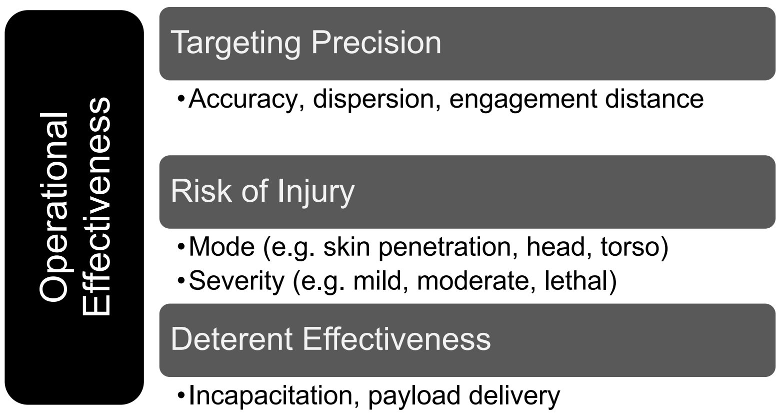

Figure 2: Factors in determining operational effectiveness of less-lethal munitions.

The outcome of any one of the factors is dependent on the distance of engagement with the targeted person with associated minimum and maximum distances for optimal performance. However, the optimal distances vary for each factor and a compromise is typically required to establish a recommended operational range as shown in the illustration below.

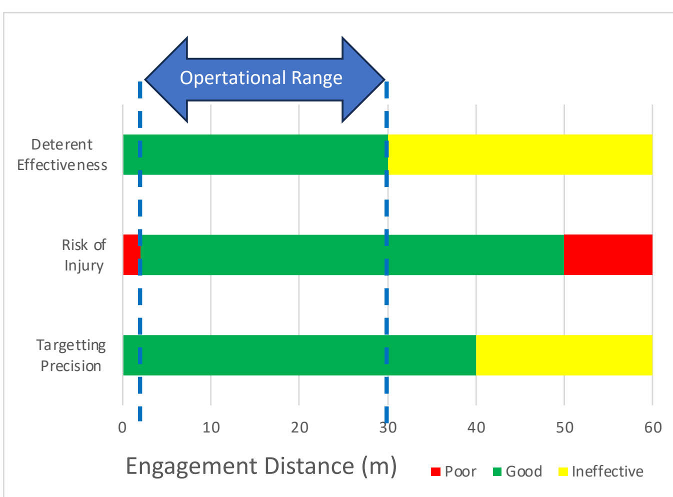

Figure 3: Illustration of operational range for effective engagement.

Each performance factor must be evaluated to quantify the range of engagement using scientific methods where possible to provide confidence and traceability of the results. As such, standards organizations and scientific agencies have developed test methods and performance metrics for NLKE munitions over the past many decades to provide the needed confidence and traceability as well as a consistent means to assess performance, whether it be targeting precision or injury risk. This need has been realized with the publication of the NATO Standardization Office (NSO) list of recommended test methods to assess the risks of using NLKE munitions across the full spectrum of operational requirements, mission areas and operating environments. The test procedures are grouped under the “Standardization Recommendation STANREC 4744 - Risk Assessment of Non-lethal Kinetic Energy Projectiles” and includes the following four Allied Engineering Publications (AEP) [NATO 2021a, NATO 2021b, NATO 2021c, NATO 2021d]:

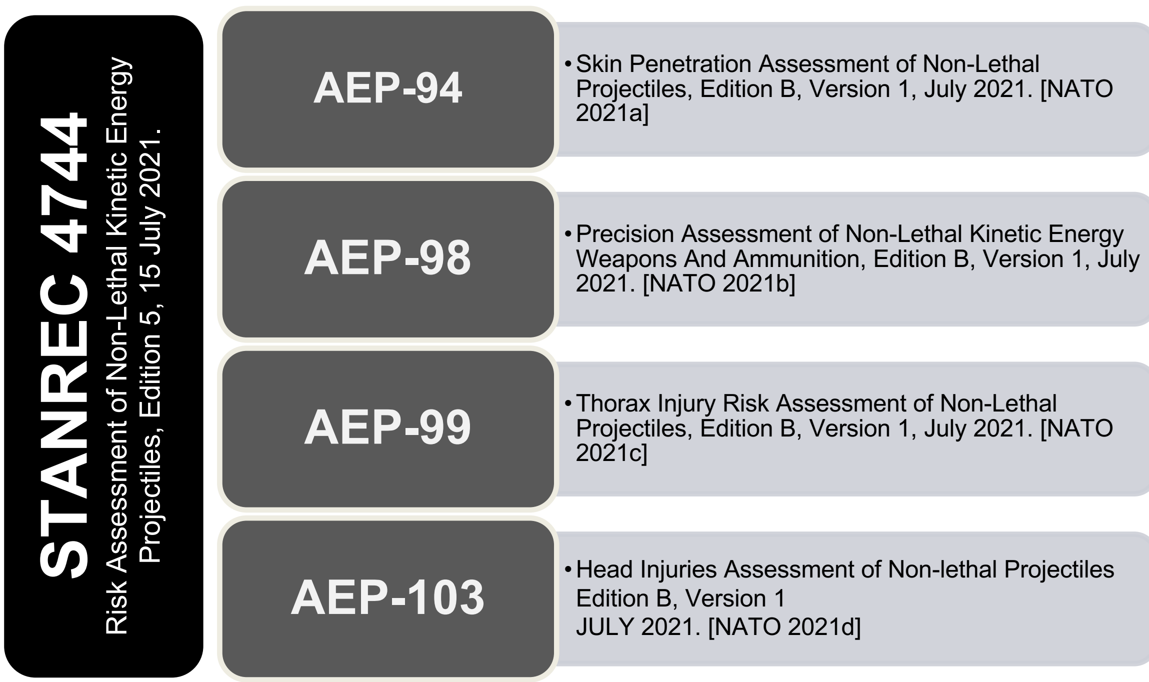

Figure 4: Test and evaluation methods provided under NATO STANREC 4744.

The AEP publications are intended to standardize the evaluation methodology for each performance aspect with thresholds suggested or referenced. However, it is the responsibility of the agency utilizing the publication to establish suitable performance criteria meeting their specific operational objectives. Furthermore, the publications are not meant to be prescriptive with regard to the technical operating procedures used, but instead, they are meant to identify suitable performance metrics and the typical means by which these can be obtained with consideration to applicability and reproducibility in order to inform decision makers and risk management processes. It may also be noted that while NATO STANREC 4744 outlines criteria and thresholds for each assessment, they also acknowledge that there are inherent uncertainties and limitations in the data and models used, and that the results should be interpreted with caution and professional judgment.

Other organizations, such as the ASTM E54 Committee on Homeland Security Applications are also developing voluntary consensus-based standards for the testing and evaluation of non-lethal kinetic energy projectiles (https://www.astm.org/). The standards are initiated and formalized through working groups attended by stakeholders, and upon completion, are published as a formal test methods for reference by regulating agencies. The scope of evaluation is currently limited to targeting precision and energy measurement with the publication of the following standard:

- **ASTM E3276/E3276M-21**[3], Standard Test Method for Assessing Impact Energy and Precision of Direct-fire, Single-projectile Less Lethal Impact Rounds Used by Public Safety Officers

Additional efforts are underway to further define test methods for penetration risk and thoracic blunt trauma assessment but are at the initial stages of development. Development of these standards are the responsibility of working groups attended by law enforcement user representatives, regulators, scientists, practitioners and standards bodies. The following working group is responsible for the less-lethal impact munitions effort:

- **ASTM WK70043**[4], New Specification for the Safety of Targeted Individuals During Deployment of Less Lethal Impact Devices used by Law Enforcement

In the absence of timely standardized and prescriptive test procedures, research agencies, test laboratories and industry may resort to internal technical operating procedures to ensure consistency, traceability and confidence in the test results. One such procedure, Biokinetics' "Standard Operating Procedure for NATO Standard AEP-99 - Thorax Injury Risk Assessment of Non-lethal Projectiles", was developed by incorporating the technical requirements of STANREC 4744 AEP-99[5] but with additional consideration of internal test procedures encompassing equipment setup, validations, sample preparation and testing, along with quality management and reporting practices.

[3] https://www.astm.org/e3276_e3276m-21.html
[4] https://www.astm.org/workitem-wk70043
[5] Biokinetics and Associates Ltd., "Standard Operating Procedure for NATO Standard AEP-99 - Thorax Injury Risk Assessment of Non-lethal Projectiles", Document: BAL AEP-99 SOP, Edition B, Ver. 1, 2024.

6. Thoracic Injury Risk Assessment

Injuries from NLKE ammunition have resulted in serious or fatal consequences with contusions, fractures and penetrating injuries being reported [Kapeles 2019, #18]. Thoracic injuries from NLKE ammunition reported in the literature between 1972 -2009 included lung contusions, hemothorax and pneumothorax, and cardiac, with some fatalities involved. Another study reviewing data from 1990-2017 reported injuries involving permanent disability and death with many being attributed to metal-rubber and plastic-metal matrix bullets as well as bean bags containing lead shot.

The range of injuries and severities experienced with NLKE ammunition is varied depending on the speeds, mass and size of the projectiles, necessitating the need to evaluate their injury potential. For example, 40 mm projectiles are thought to have less penetrating potential than smaller caliber projectiles but can still result in intramuscular bruising [Kapeles 2019] and very significant blunt trauma [Robbe 2023]. Typical commercial 40 mm ammunitions have been noted to have a mass range of 20-100 g with launch speeds of 70-140 m/s and may have compliant impact faces to manage energy transfer [Robbe 2023]. This suggests that the injury potential of each ammunition needs to be assessed individually to determine their performance characteristics along with consideration of influences from their operational environment.

6.1 AEP-99 - Thorax Injury Assessment Test Method

As part of the suite of less-lethal impact munition performance evaluation methodologies developed by STANREC 4744 (Figure 4), the AEP-99 test method has been developed to quantify the blunt force impact injury risk to the thorax. The injury assessment is limited solely to rib and sternal fractures due to the limited availability of biomechanical tolerance [NATO 2021c].

The test setup requires the NLKE projectile to be launched into a biofidelic surrogate that is instrumented to measure chest compression, Figure 5. The surrogate is validated against the specified performance requirements including a deflection-time corridor and an allowable Viscous Criterion (VC) interval. Injury assessment is based on the maximum value $(VC)_{max}$. The VC is based on the product of compression and velocity of the chest wall at each instance in time to characterize the dynamic response of the human and injury outcome from high-rate impact conditions. The VC was originally developed for injury analysis of ballistic and less-lethal blunt impacts with a 37 mm plastic baton launched onto cadavers [Bir 2000] [Bir 2004].

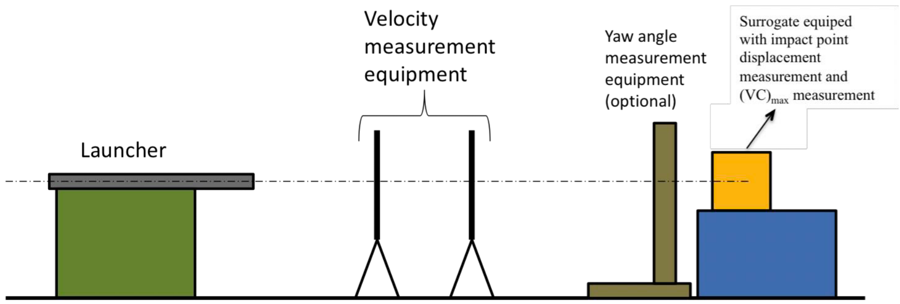

Figure 5: Experimental setup for the evaluation of thoracic injury [NATO 2021c].

The torso surrogate used for current evaluations is the BTTR (Blunt Trauma Torso Rig) developed by Biokinetics with the support of the Defence Research and Development Canada (DRDC), Valcartier [Anctil 2008] and the Technical Support Working Group[6], see Figure 6. The surrogate is recommended for use with AEP-99 testing due to its repeatability and robustness [Robbe 2023]. The compression of the compliant torso membrane is measured with a non-contact laser sampled at 10 kHz and filtered with a nominal 1000 Hz low-pass filter, (SAE J211-1: CFC 1000). The compression data is then differentiated to derive the instantaneous velocity which is then multiplied by the compression at the same instance to compute the Viscous Criterion (VC) as further described in Section 6.2. A protective layer of Kevlar® is used during testing to prevent surface damage and abrasions to the BTTR.

The BTTR was demonstrated by Biokinetics to meet the deflection response biofidelity corridors proposed by Bir (2000) as derived from PMHS tests with a 37 mm rigid plastic baton and independently verified by Robbe (2016), Figure 7, using the same biofidelity corridors of Bir (2000) as referenced in AEP—99 for validating numerical simulations of thoracic surrogates. An alternative biofidelity corridor presented in AEP-99 employs a deformable projectile (e.g. B&T SIR—X) but is not currently used due to the limited availability of the ammunition, limited biomechanical traceability and dependency on the dynamic compliance of the projectile requiring validation of the projectile itself prior to testing.

[6] Renamed to the Irregular Warfare Technical Support Directorate (https://www.cttso.gov/).

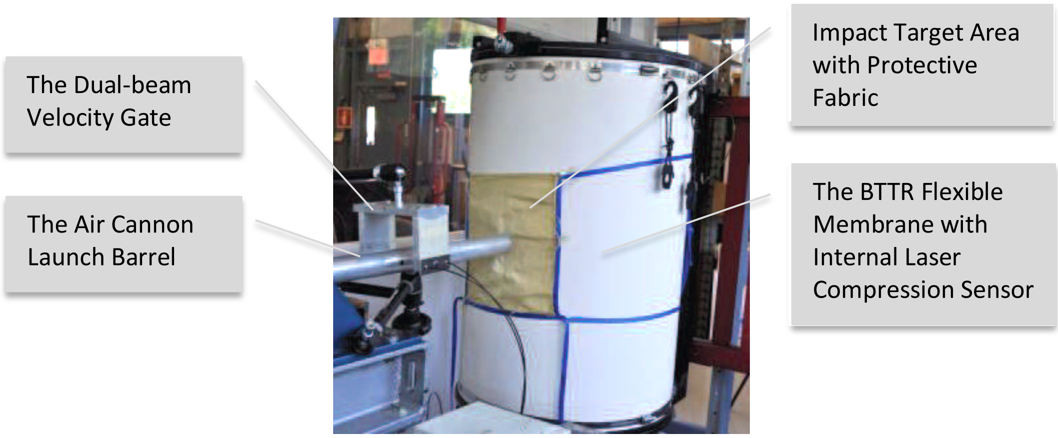

Figure 6: The Blunt Trauma Torso Rig (BTTR) [Anctil 2016].

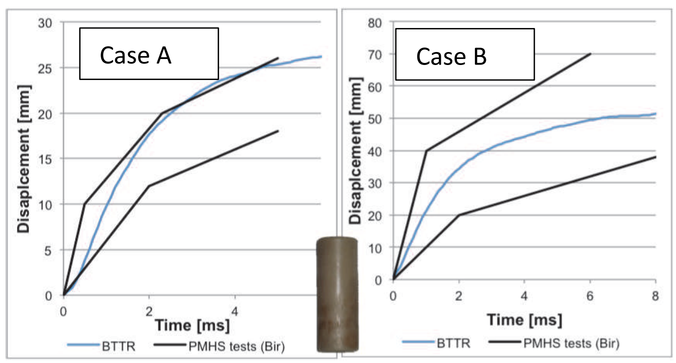

Figure 7: Dynamic deflection response of the BTTR compared to PMHS corridors for Case ‘A’ (37 mm dia., 134.5 g, 20 m/s) and Case ‘B’ (37 mm dia., 134.5 g, 40 m/s) [Robbe 2016].

Biokinetics experimental equipment is similar to that specified above with details provided below in Table 1. The NLKE launcher is replaced with a smooth bored air cannon capable of launching the projectile body (without cartridge) at equivalent speed and yaw conditions seen with typical launchers but without the effects of gyroscope stability from rifled barrels, if they exist. Projectile targeting is well controlled (<3 mm) as is yaw (<5°) due to the short distance between the barrel and surrogate (typically 387 mm). The shot targeting and yaw are confirmed at the beginning of a test series or setup.

Table 1: Experimental equipment used to measure projectile parameters.

Description	Device
Projectile Speed	Biokinetics dual beam light gate located at the muzzle. Beam spacing 50.8 mm, sampling rate 10 kHz.
Projectile Yaw	High-speed video, 2000 frames/sec
Projectile Obliquity and Targeting	Dictated by alignment of the air cannon barrel and target, 90 degrees obliquity, ±3 mm placement repeatability and ±5˚ yaw

All tests are conducted at ambient temperature. A total of 10 NLKE impacts are conducted and analysed per AEP—99 to obtain the mean response and upper value under which 99% of the data will fall, with 95% confidence [NATO 2021c] [Robbe 2023]. The best practices set out in Biokinetics' Standard Operating Procedure (BAL AEP-99 SOP) are used to guide testing [Biokinetics 2024].

Prior to testing with NLKE munitions, pre-test validation of the BTTR is conducted to confirm its operation and performance. The biofidelity corridors according to Bir (2000) (37 mm diameter baton at 40 m/s) was selected for comparison. All impacts are conducted within the validated target area of the membrane, i.e. mid-height.

6.2 Injury Assessment with the BTTR

Injury assessments with the BTTR are in accordance with the Viscous Criterion (VC) calculations as stipulated in AEP-99 [NATO 2021c] and further detailed by Robbe (2018) for use with less-lethal impact munitions:

Viscous Criteria (VC) $(VC)_{BTTR\ external} = V(t)\ [C(t)/C_{ref}]_{\ internal} * 0.432$

where:

$V(t)$ = the instantaneous velocity computed from the chest compression $C(t)$ (m/s)

$C(t)$ = the instantaneous chest compression (mm)

C_{ref} = the chest depth normalization factor (mm), 236 mm for a 50^{th}% male

The chest velocity is derived from the measured chest compression using a weighted moving averaging scheme to reduce noise as specified by Anctil (2008).

$$V(t) = \frac{8\left[C(t+\delta t) - C(t-\delta t)\right] - \left[C(t+2\delta t) - C(t-2\delta t)\right]}{12\delta t}$$

Limitations stated in AEP-99 include that the VC has not been validated for impacts greater than 60 m/s (197 ft/s) and that it is only applicable for assessing skeletal fractures. This is meant to provide limitations on the interpretation of absolute injury risk and not necessarily negate the use of VC for less-lethal projectile injury analysis. Furthermore, the AEP-99 utilizes the VC for all thoracic impact tests including validation tests up to 86.5 m/s (284 ft/s) with the B&T Sir-X munition. However, the utility of the BTTR has been demonstrated in its extensive assessment of VC for investigating the performance of 40 mm NLKE munitions to over 100 m/s [Robbe 2023].

The injury severity is assessed in AEP-99 using the international consensus based Abbreviated Injury Scale, also known as the AIS [AIS 2015] originally developed for vehicular accidents. The AIS classifies an injury description according to the body region and type along with a corresponding severity on a six point scale with 1=minor, 2=moderate, 3=serious, 4=severe, 5=critical, 6=maximal. It is based partly on the threat-to-life and other components including energy dissipation, tissue damage, treatment period, impairment, and quality of life, where applicable. As such, the AIS score performs well as a measure of mortality but is not the sole determinant.

The application of the AIS to less-lethal kinetic energy munitions was accomplished by impacting cadavers with less-lethal rounds and then associating the injury type and severity with the AIS 2015 ranking. In the study by Bir (2004b), AIS 2 or 3 severity injuries were determined from cadavers (average age=70.9 years, 5 male, 5 female) with a the 37 mm, 140 g plastic baton [Bir 2004b]. The risk of injury was then estimated with statistical methods where a sigmoidal function is used to relate the $(VC)_{max}$ value to the probability of a specific injury (i.e. AIS 2, 3). It is expressed as:

$$\text{(Probability of AIS 2, 3)} = 100 * [1 + \exp(-\alpha -(\beta x)]^{-1} \ \ (\%)$$

For an AIS=2 or AIS=3 injury risk level, α = -4.34 and β = 5.58 , illustrated below in Figure 9. The 50% probability of sustaining a thoracic skeletal fracture (1-2 ribs or sternum) occurs approximately with $(VC)_{max}$=0.8 for the group of PMHS tested, as referenced in AEP-99.

6.3 Thoracic Injury Research

As part of the ongoing effort to evaluate, predict and prevent injuries caused by NLKE munitions, the thorax was one of the first body regions to be studied [Bir 2000]. Three impact conditions were established using a 37 mm diameter rigid plastic baton impactor: (a) 140 g mass at 20 m/s; (b) 140 g mass at 40 m/s, and; (c) 30 g mass at 60 m/s. The bodily response of cadavers was characterized by the force-time, deflection-time and force-deflection relationships. The Viscous Criterion (VC) was determined to adequately predict the risk of injury from blunt ballistic impacts. Reanalysis of earlier data first collected by Cooper and Maynard (1986) indicated that a VC=2.8 predicted a 25% risk of severe lung injury. A 50% risk of a less severe skeletal injury of 1-2 rib fractures or simple sternal fracture (AIS=2, 3) was predicted by a VC=0.8 [Bir 2004] and is currently referenced in AEP-99 for context and not as an absolute performance threshold.

At this time, the Bir (2000) data remains the most trustworthy and adequate scientific data source for developing a NLKE impact munition thoracic injury evaluation methodology and remains as the primary reference for biofidelity and injury assessment in AEP-99 [Robbe 2023].

6.4 Summary of Test Results of the ARWEN AR40-1

A test program was conducted on July 17, 2024 for KWESST on the ARWEN AR40-1 less-lethal munitions to assess the thoracic blunt impact injury risk. A nominal impact test velocity of 70 m/s (230 ft/s) was stipulated and represents the rated muzzle velocity. The test results are provided in the Biokinetics' Test Report No. TR2430 KWESST.

Prior to testing, validation of BTTR surrogate's compliance with the test conditions stipulated in AEP-99 (37 mm plastic baton of 140 g, nominal impact speed of 40 m/s) must be demonstrated. The test results from a prior compliance study are depicted in Figure 8 showing a mean of 10 shots with a $(VC)_{max}$=0.738 and with an upper interval of $(VC)_{max}$=1.083 which represents the value at which 99% of the data will fall below, with 95% confidence (as computed per AEP-99). It was confirmed that the mean $(VC)_{max}$ and upper interval fall within the allowable limits.

Figure 8: BTTR surrogate validation results compared to AEP-99 requirements.

Assessment of thoracic blunt impact injury risk with the less-lethal munitions was then conducted with a total of 10 fair shots. For the ARWEN AR40-1, impact speeds were in the range of 69.3-71.6 m/s, Table 2. The mean $(VC)_{max}$ =1.27 was obtained and represents a 94% risk of AIS=2, AIS=3 injury as provided in Table 2 and illustrated in Figure 9. The upper limit below where 99% of the $(VC)_{max}$ results would result was estimated to be $(VC)_{max}$=1.55 as determined according to the AEP-99 methodology with a 95 percent confidence interval.

Table 2: Thoracic impact results of the KWESST – ARWEN AR40-1 on the BTTR.

Serial	Fair	m/s	$(VC)_{max}$	C_{max} (mm)	AIS 2+
1	Y	70.20	1.31	78.60	*95%*
2	Y	69.80	1.28	78.40	*94%*
3	Y	70.80	1.23	82.20	*93%*
4	Y	69.00	1.35	81.70	*96%*
5	Y	70.10	1.34	81.60	*96%*
6	Y	71.60	1.28	79.80	*94%*
7	Y	70.70	1.27	80.60	*94%*
8	Y	69.90	1.28	78.80	*94%*
9	Y	69.30	1.10	80.50	*86%*
10	Y	69.70	1.28	76.90	*94%*

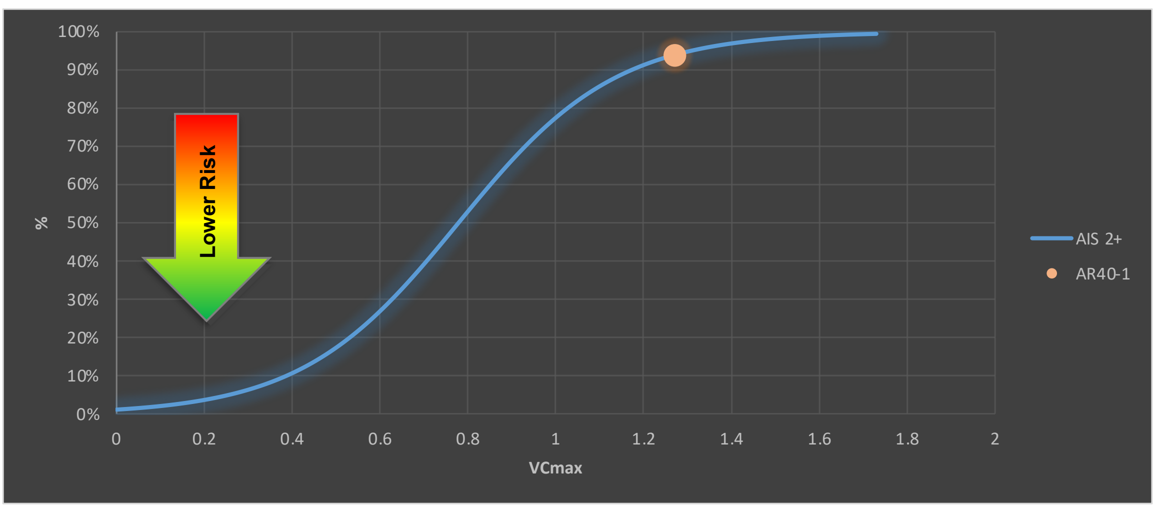

Figure 9: ARWEN AR40-1 injury risk assessment for BTTR impacts at a nominal 70 m/s.

6.5 Discussion

The ARWEN AR40-1 non-lethal kinetic energy munitions were evaluated for thoracic blunt impact injury risk per the requirements of AEP-99 [NATO 2021c]. The assessment was based on the probability of experiencing an AIS 2 or 3 injury based on the fracture of 1-2 ribs or sternal fracture only. Injuries to the internal organs or cardiac system are not addressed by AEP-99 as these are considered to require more aggressive impacts with corresponding higher values of $(VC)_{max}$ to cause the same severity of injury. A total of 10 fair shots were conducted at a strike velocity representative of the muzzle velocity. A mean value of $(VC)_{max}$=1.27 was obtained for the ARWEN AR40-1 munition and represents a 94% risk of AIS 2 or 3. It is important to note that the AIS values are inferred from testing with an elderly population who typically exhibit lower tolerance to skeletal fractures. With this, and that AIS 2 or AIS 3 injuries pose a low threat-to-life with expected full recovery, the ARWEN AR40-1 munition can be operated within its stated operational range with low associated risk of thoracic blunt impact injury.

For reference, it may also be noted that the 50% risk of AIS 2 or 3 injury with a $(VC)_{max}$=0.8 provided in Bir (2004b), and cross-referenced in AEP-99 [NATO 2021c], should be used for reference only as it represents typical values for the elderly cadaveric sample used in the study. The threshold of injury will vary according to age, sex, size, and health of an individual. The acceptable risk of injury should also be dictated by the agency utilizing the NLKE munition due to specific operational requirements and circumstances outside the control of the NLKE manufacturer. Operational conditions such as the available stand-off, targeting precision, effectiveness of deterrent, payload delivery, and training should be considered in the guidelines for their use and defining the acceptable risks.

Based on the current tests, the ARWEN AR40-1 munition presents a 94% risk of injury at the AIS 2 to AIS 3 severity to the thorax based on skeletal damage (rib or sternal fracture).

The ARWEN AR40-1 munition impacted at 70 m/s (230 ft/s) were shown to have a 94% risk of AIS 2 or AIS 3 which is associated with low injury severity involving rib or sternal fracture.

7. Summary

Thoracic Blunt Impact Injury Risk

The ARWEN AR40-1 munition was evaluated for thoracic skeletal injury per the requirements of STANREC 4744 AEP-99. A total of 10 fair shots were conducted for the munition at a strike velocity representative of muzzle velocity. A mean value of $(VC)_{max}$=1.27 was obtained for both munitions, representing a 94% risk of AIS 2 or 3 injury severity for the thorax based on skeletal damage (rib or sternal fracture).

The ARWEN AR40-1 munition impacted at 70 m/s (230 ft/s) were shown to have a 94% risk of AIS 2 or AIS 3 which is associated with low injury severity involving rib or sternal fracture.

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