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Non-Lethal Weapons

Opportunities for R&D

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Technical Memorandum

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Abstract

The aim of this overview study is to recommend the Non-Lethal Weapon (NLW) research and development that Defence Research and Development Canada (DRDC) could conduct over the next decade (and possibly beyond) in response to emerging defence and security NLW requirements. It summarizes the DRDC perspective of NLW technologies, which includes non-lethal applications of electro-magnetic and acoustic directed energy. The study shows that by channeling existing expertise and effort, DRDC could, over time, provide the Canadian Forces with science and technology knowledge on the effects, operational effectiveness and counter-measures of selected, emerging NLW technologies.

Résumé

La présente étude d'ensemble a pour objet de recommander les travaux de recherche et développement sur les armes non létales (ANL) que Recherche et développement pour la défense Canada (RDDC) pourrait effectuer au cours des dix prochaines années (et peut-être au-delà) pour satisfaire aux nouveaux besoins d'ANL en vue d'assurer la défense et la sécurité. Elle résume la perspective de RDDC sur les technologies d'ANL, notamment les applications non létales de l'énergie électromagnétique et acoustique dirigée. L'étude montre que si elle canalise l'expertise et le travail actuels, RDDC pourrait, au fil du temps, fournir aux Forces canadiennes des connaissances scientifiques et technologiques sur les effets, l'efficacité opérationnelle et les contre-mesures liées à certaines technologies nouvelles en matière d'ANL.

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Executive summary

Non-Lethal Weapons (NLW) comprise a strategic objective in the Technology Investment Strategy that guides the Defence Research and Development Canada (DRDC) research and development (R&D) program. For the past decade, DRDC has conducted a technology watch as its main NLW activity. The rise in Peace Support Operations and non-state terrorism has increased the need for non-lethal military options and called into question the appropriateness of DRDC continuing only a NLW technology watch. Consequently, DRDC commissioned the study "Non-Lethal Weapons: Opportunities for R&D" to recommend R&D that DRDC could conduct over the next decade (and possibly beyond) in response to emerging defence and security NLW requirements.

The study consists of an overview of Canadian Forces (CF) NLW policy, doctrine and requirements and a number of technical papers describing the non-lethal applications and potential areas of R&D for the major areas of the non-lethal technology taxonomy or classification, which includes non-lethal applications of electro-magnetic and acoustic directed energy. The study recognizes that NLWs is a new and evolving capability that is faced with many difficult military, scientific, legal and ethical issues. R&D alone cannot resolve these issues, but can inform the debate by providing sound scientific data on NLW effects.

NLW science and technology (S&T) is evolving rapidly. Meaningful information on NLW effects is difficult to obtain from allies unless data of comparable scientific value is exchanged in return, for which a national NLW R&D program is usually required. It is therefore, in the CF interest to conduct NLW R&D. The DRDC technology watch indicates the key S&T challenges facing NLW R&D are as follows:

- First, there is a scarcity of well-documented human and materiel target response data on the various NLW technologies. While there are many references to NLW effects, the scientific value of these observations and conclusions is difficult to validate. Moreover, the development and potential application of non-lethal and directed energy technologies is outpacing the understanding of their effects. In particular, the human physiological and psychological effects of many NLW technologies, in both the short term and long term, are not well understood.

- Secondly, the lack of standardization in data collection and in research protocols, both of which are considered essential, complicates collaboration and transfer of existing data both within and between nations.

- Thirdly, even when the effects of NLW technologies are known, modeling and simulation (M&S) tools are needed to assess NLW operational effectiveness in realistic employment scenarios and to analyze the cost/benefit ratio of the R&D investment for the CF. These tools are difficult to develop, in part because the effects data needed to populate and exercise them have not been collected.

- Lastly, the right to self-defence is never denied and counter-measures against non-lethal attacks may become an important force protection measure. The requirement may be particularly acute when the opposing force's NLW inventory is more extensive or advanced than that of the CF and where the adversary uses chemical and biological NLWs that other states may consider illegal or prohibited.

DRDC possesses the skills and expertise to move from a technology watch to active NLW R&D. The knowledge gained in blunt trauma, operational medicine, directed energy and the human response to chemical hazards can be leveraged for NLW applications. Some scientific skills are more transferable than others, and time will always be needed to become familiar with the technological issues and barriers facing NLW R&D. Nevertheless, the R&D focus should be on the key technical challenges of gathering effects data, defining data requirements, assessing operational effectiveness and developing counter-measures. The actual non-lethal application should be assessed on its scientific value, enhanced operational effectiveness and timely delivery. Full use should be made of international cooperative R&D programs to enhance the DRDC NLW program through lessons learned and insights gained by allies.

The study draws the following conclusions:

- The evolving operational environment since the end of the Cold War has made NLWs a new and pressing military requirement;
- Developments in many technology areas have advanced to a point where the potential for many NLW applications can now be seen;
- International studies have indicated that the major technological challenges facing NLW R&D are: the scarcity of well-documented target response data to the various NLW technologies; NLW effects data requirements; the lack of modelling and simulation tools to assess the operational effectiveness; and, NLW counter-measures.
- DRDC expertise in lethal weapon, protective measures and human performance R&D is applicable to many areas of the NLW technology taxonomy; and
- Legal and ethical constraints must be respected in NLW R&D.

The study recommends that DRDC conduct active R&D in selected NLW technology areas with the objectives of:

- assessing NLW target effects;
- defining standardized effects data requirements;
- recommending M&S tools to assess operational effectiveness; and,
- identifying counter-measures.

An R&D program that addresses these objectives will allow DRDC, over time, to provide the CF with S&T knowledge on the effects, operational effectiveness and counter-measures of selected, emerging NLW technologies.

Stocker, H., LCol Dick, J. B. and Berube, G. 2004. Non-Lethal Weapons: Opportunities for R&D. 2004-006. Defence R&D Canada.

Sommaire

Les armes non létales (ANL) constituent un objectif stratégique dans la Stratégie d'investissement technologique qui oriente le programme de recherche et développement (R & D) de Recherche et développement pour la défense Canada (RDDC). Au cours de la dernière décennie, la principale activité de RDDC en matière d'ANL a consisté en une veille technologique. La montée des opérations de soutien de la paix et du terrorisme non étatique a intensifié le besoin d'options militaires non létales et a remis en question l'opportunité pour RDDC de continuer à limiter son activité liée aux ANL à de la veille technologique. Par conséquent, RDDC a commandé une étude sur les armes non létales et les occasions de R & D, afin qu'on lui recommande des travaux de R & D qu'elle pourrait mener au cours des dix prochaines années (et peut-être au-delà) afin de satisfaire aux nouveaux besoins d'ANL en vue d'assurer la défense et la sécurité.

L'étude consistait en un survol de la politique, de la doctrine et des besoins des Forces canadiennes (FC) en matière d'ANL ainsi qu'en un certain nombre de documents techniques décrivant les applications non létales et les domaines éventuels de R & D pour les principaux secteurs de la taxonomie ou classification des technologies non létales, dont les applications non létales de l'énergie électromagnétique et acoustique dirigée. On reconnaît dans l'étude que les ANL constituent une nouvelle capacité en pleine évolution qui suscite de nombreux dilemmes d'ordre militaire, scientifique, juridique et éthique. La R & D ne peut, à elle seule, régler ces questions, mais elle peut éclairer le débat en fournissant des données scientifiques fiables sur les effets des ANL.

La science et la technologie (S & T) concernant les ANL évoluent rapidement. Il est difficile d'obtenir des alliés des renseignements valables sur les effets des ANL, à moins que des données de valeur scientifique comparable puissent leur être fournies en échange, et pour ce faire, il faut habituellement un programme national de R & D sur les ANL. Les FC ont donc intérêt à effectuer de la R & D sur les ANL. Voici, selon la veille technologique de RDDC, les enjeux clés de S & T qui se posent relativement à la R & D sur les ANL.

- Premièrement, il existe peu de données bien documentées liées aux effets sur les objectifs humains et matériels des diverses technologies d'ANL. Certes, les références sur les effets des ANL sont nombreuses, mais il est difficile de confirmer la valeur scientifique de ces observations et conclusions. En outre, le développement et l'application éventuels des technologies non létales et à énergie dirigée devancent la compréhension de leurs effets. Plus particulièrement, les effets humains physiologiques et psychologiques de nombreuses technologies d'ANL, tant à court terme qu'à long terme, ne sont pas bien compris.

- Deuxièmement, l'absence d'uniformisation dans la collecte des données et dans les protocoles de recherche, deux aspects jugés essentiels, complique la collaboration et le transfert des données actuelles au sein des pays et entre ceux-ci.

- Troisièmement, même quand les effets des technologies d'ANL sont connus, il faut disposer d'outils de modélisation et de simulation (M & S) pour évaluer l'efficacité opérationnelle des ANL dans des scénarios d'utilisation réalistes et pour analyser le

rapport coûts/avantages de l'investissement dans la R & D pour les FC. Ces outils sont difficiles à développer parce que, entre autres, les données sur les effets requises pour les alimenter et les mettre en pratique n'ont pas été recueillies.

- Finalement, le droit de légitime défense n'est jamais dénié, et les contre-mesures en cas d'attaques létales peuvent devenir une importante mesure de protection de la force. Ce besoin peut devenir particulièrement pressant lorsque les stocks d'ANL de la force d'opposition sont plus grands ou plus avancés que ceux des FC et lorsque l'adversaire utilise des ANL chimiques et biologiques que d'autres États peuvent juger illégales ou interdites.

RDDC possède les compétences et l'expertise nécessaires pour passer d'une veille technologique à une R & D active en matière d'ANL. Les connaissances acquises dans les domaines des traumatismes fermés, de la médecine opérationnelle, de l'énergie dirigée et de la réaction humaine aux risques chimiques peuvent être mises à profit pour les applications d'ANL. Certaines compétences scientifiques sont plus facilement transférables que d'autres, et il faudra toujours du temps pour se familiariser avec les problèmes et obstacles technologiques qui se poseront dans la R & D sur les ANL. Néanmoins, la R & D devrait être axée sur les enjeux techniques clés de la collecte de données sur les effets, de la définition des besoins en données, de l'évaluation de l'efficacité opérationnelle et de l'élaboration de contre-mesures. En fait, l'application non létale devrait être évaluée en fonction de sa valeur scientifique, de l'amélioration de l'efficacité opérationnelle et de la rapidité d'exécution. Il faudrait aussi utiliser au maximum les programmes de coopération internationale en matière de R & D pour améliorer le programme d'ANL de RDDC, au moyen des leçons retenues et de l'expérience acquise par les alliés.

Les conclusions suivantes ont été tirées de l'étude.

- En raison de l'évolution de l'environnement opérationnel depuis la fin de la guerre froide, les ANL constituent maintenant un besoin militaire nouveau et pressant.
- Les développements survenus dans bien des secteurs technologiques ont atteint un point où il est maintenant possible d'envisager de nombreuses applications pour les ANL.
- Des études internationales ont révélé que la R & D en matière d'ANL fait face aux principaux défis technologiques suivants : la pénurie de données bien documentées liées aux effets sur l'objectif des diverses technologies d'ANL, les besoins en données sur les effets des ANL, l'absence d'outils de modélisation et de simulation pour évaluer l'efficacité opérationnelle et les contre-mesures propres aux ANL.
- L'expertise de RDDC en ce qui concerne les armes létales, les mesures de protection et la R & D sur les performances humaines peut être appliquée à bien des domaines de la taxonomie des technologies d'ANL.
- Il faut respecter les contraintes d'ordre juridique et éthique dans la R & D sur les ANL.

Il est recommandé dans l'étude que RDDC se livre à une R & D active dans certains domaines de la technologie des ANL et qu'elle se donne les objectifs suivants :

- évaluer les effets sur l'objectif des ANL;

- définir des besoins normalisés en données sur les effets;
- recommander des outils de M & S pour évaluer l'efficacité opérationnelle;
- identifier des contre-mesures.

Un programme de R & D qui réalise ces objectifs permettra à RDDC, avec le temps, de fournir aux FC des connaissances scientifiques et technologiques sur les effets, l'efficacité opérationnelle et les contre-mesures de certaines des nouvelles technologies en matière d'ANL.

Stocker, H., LCol Dick, J.B. and Berube, G. 2004. Non-Lethal Weapons: Opportunities for R&D. 2004-006. Defence R&D Programs.

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1 Introduction

1.1 Background

Defence Research and Development Canada (DRDC) provides the Canadian Forces (CF) and Department of National Defence (DND) with ongoing knowledge on current and emerging science and technology (S&T) in order for the CF and DND to harness and anticipate the capabilities inherent in these technologies. Within DRDC programs, the Director Science and Technology Policy, under its Technology Outlook Thrust, carries out focused studies to assess current and emerging technologies in the context of Canadian defence and national security. This study, Non-Lethal Weapons: Opportunities for R&D, is one of these studies. It was commissioned by the Technology Assessment Working Group (a group, generally at the Chief Scientist level from the DRDC Research Centres, that promotes excellence and innovation in Defence S&T by recommending, monitoring and reporting on DRDC's Technology Investment Strategy), and mandated to examine the technologies involved with Non-Lethal Weapons (NLWs).

DRDC's Technology Investment Strategy (TIS), which outlines the R&D required to develop the science and technology capacity needed for future defence and national security, treats NLWs as a strategic objective under the Weapons Performance and Countermeasures activity [1]. In practice, NLWs have been the subject of a "technology watch" within DRDC, coupled with limited funding and sporadic testing of devices and processes, at various DRDC Research Centres. The CF participation in Peace Support Operations, evolving military requirements and the rise of non-state terrorism have all contributed to the need to re-evaluate whether there is a more appropriate response to NLW R&D than the technology watch maintained by DRDC since the mid-1990's.

1.2 Aim

The aim of this study is to recommend the NLW R&D that DRDC could conduct over the next decade (and possibly beyond) in response to emerging defence and security requirements for non-lethal weapons.

1.3 Scope

This study will cover the following areas:

a. NLW definition and technology taxonomy;

b. summary of NLW technology papers;

c. legal and ethical constraints;

d. evolving military NLW requirements;

e. R&D challenges;

f. leveraging current DRDC NLW expertise;

g. conclusions; and

h. recommendations on future NLW R&D.

2 NLW Definition and Technology Taxonomy

The CF defines NLWs as:

"Weapons, munitions and devices that are explicitly designed and primarily employed so as to incapacitate personnel or materiel, while minimizing fatalities, permanent injury to personnel and undesired damage to property and the environment. This definition does not include information operations (e.g., jamming, psychological operations, etc.) or any other military capability not designed specifically for the purpose of minimizing fatalities, permanent injury to personnel, and undesired damage to the environment, even though these capabilities may have non-lethal effects (e.g., smoke and illumination)."[2]

Other terms are also used to describe the effects or capabilities possessed by NLWs. In law enforcement situations, "Less-Lethal Weapon" is more often used than NLW. The term "Non-Lethal Capability" is also found in situations to describe non-lethal requirements. "Non-Lethal Techniques" are used to describe situations where non-violent means may be used to resolve problems. Directed energy weapons are a class of weapons that have both lethal and non-lethal effects, depending at which end of their power spectra is used. They form a subset of NLWs when developed for their non-lethal applications in accordance with international law. For simplicity, this report will use NLWs to encompass all these terms.

The taxonomy of NLW technologies is quite varied. It spans chemistry (e.g. obscurants, reactants, foams, pharmaceutical/calmatives), mechanical and kinetic energy transfer (e.g. barriers, entanglements, blunt impact devices), electrical (electrical, radio frequency, microwave, infrared, visible, ultraviolet) and acoustic (infra-sound, audible, ultra-sound) energy and some ancillary applications as well (markers, non-lethal casings). The Technology Taxonomy table produced by the NATO study on assessment of NLW effectiveness[3] is at Annex H.

3 Summary of NLW Technology Papers

This study produced a number of technical papers describing the non-lethal applications of many of the technologies found in the taxonomy. Generally, each the papers was prepared by a different technical specialist at a DRDC Research Centre each of whom has significant background and detail on the particular technology. Since these papers were produced independently different formats and writing styles can be expected, as well as some overlap and possible contradictions in technical issues. The individual authors are responsible for the content of their papers. The following paragraphs summarize the technologies described in the papers and illustrate opportunities for future NLW R&D. These papers support the conclusions and recommendations made at the end of study. The complete papers are attached at Annexes A to G.

3.1 Non-Conventional Weapons Study: Kinetic Energy Non-Lethal Weapons (Annex A)

Kinetic energy NLWs are intended to inflict pain and incapacitation on a target (a person) by impacting it with a projectile (e.g., rubber bullet, baton round, etc.) or a hand-held baton or truncheon. This annex deals mainly with the projectile-type NLWs, whose efficacy is influenced by a number of factors (calibre, size, weight, impact velocity, shape and material properties) related to the projectile, as well as the health condition, age and location of the body impacted. Psychological impacts on the targets are varied and difficult to assess. Good scientific data are sparse and non-reproducible, often anecdotal, and come from a wide variety of international sources (single and unrelated incidents, crowd or riot control initiated by police or defence forces, injuries in sports, accidents in the defence, automotive and aircraft domains). Kinetic Energy NLWs may be used for “point control” (to neutralize a single person at a time) or for “area or crowd control” (i.e., to neutralize many persons with one shot, employing many projectiles).

The potential R&D opportunities identified by the author are: (1) perform R&D on the physiological/psychological effects and resulting target behaviour, in order to evaluate the performance of the kinetic energy NLW; (2) carry out R&D on the injury and criteria of blunt trauma on different parts of the body (head, neck, thorax, abdomen); (3) develop test methods for evaluating, in a scientific way, the technical performance and injury potential of each weapon type, so that the data are comparable between and among laboratories; (4) develop a kinetic energy NLW that will be truly non-lethal and accurate from the discharge muzzle up to about 100m.

3.2 Laser-based Directed Energy Weapons (Annex B)

While lasers have been on the battlefield for more than 30 years, initially as rangefinders in some weapon systems, they are also being used now as dazzlers, target designators and beacons to guide laser beam rider missiles (or smart bombs, artillery shells or rockets) to their targets. Owing to the unique nature of laser light, namely its coherence, monochromatic nature, high degree of collimation and intensity, it could also be used as a directed energy weapon. Low-energy lasers can be used as anti-eye weapons, causing visual damage ranging from discomfort, glare, dazzle, and “flash” blindness, up to painful eye damage. As well, these lasers can be used in an anti-sensor role, by disabling or destroying an enemy’s sensor system. Variable wavelength or agile lasers are also more effective and resistant to countermeasures such as optical filtering. Ultra-violet lasers can also be used to ionize conductive paths in the air along which an electrical (high voltage) current can be directed toward a target, as in the Taser, which causes uncontrollable contraction of muscle tissue in the human target. High-energy lasers are developed mainly for air defence where the aim is to destroy incoming munitions or aircraft before the latter can accomplish their missions. Once the target has been identified, and the target has been “locked-on”, the laser delivers its energy in an almost zero time-of-flight manner. Thus, they are seen to be most effective in countering multiple, simultaneous threats that would normally saturate conventional air defences, based on anti-aircraft guns and missiles, though no such systems are yet operational. High energy lasers could also be used in the same role as low energy lasers to disable or dazzle sensors, electro-optical systems, human eyes at much longer ranges. However, they would not be eye safe and could therefore not be considered as non-lethal.

The potential R&D opportunities identified by the author are: (1) concentrate R&D efforts on low-energy lasers, which are affordable and where DRDC has some expertise in niche areas of development; (2) encourage Canadian industry to participate to a greater degree than at present in new laser system developments; (3) seek to contribute DRDC expertise to large, bilateral or multi-lateral R&D programs with Allies.

3.3 Chemical Counter-Materiel Non-Lethal Weapons (Annex C)

Counter-materiel non-lethal technology (which may find its way into a variety of weapons) is a general term defined as the means to disable or neutralize vehicles, vessels, aircraft, equipment and facilities. It also includes technologies that would deny an area to vehicles, vessels and aircraft. The “chemical” nature of such technologies includes organic and/or inorganic compounds developed to react with other compounds or substances and/or produce the desired effects in counter-materiel applications. The disablement or neutralization may take the form of alteration of the combustion properties of fuel, the viscosity of lubricants or the ability of vehicles to gain traction. The seven categories of chemical counter-materiel NLWs include: obscurants, reactants, anti-tractions, foams, malodorants, riot control agents and ancillary technologies. Combining the experience and related expertise of DRDC scientists in a number of the seven categories and taking into account the many legal and ethical constraints, one can identify a number of general opportunities for improving DRDC capabilities: determining the utility of chemical counter-materiel technologies for the CF; collaborating with US laboratories and other NATO countries involved in NLWs; identifying measures of effectiveness of various NLWs; conducting trials with current and promising technologies; adapting and/or developing technologies in accordance with international treaties and conventions; reducing environmental and health vulnerabilities; developing conflict-resolution strategies involving chemical NLWs.

The potential R&D opportunities identified by the author are: (1) in light of long-term potential, usefulness to the CF and existing Canadian expertise, pursue the following technologies: combustion alteration, rigid foams, thermite propellants, certain obscurants, and possible combinations of several chemical counter-materiel NLWs; (2) focus on chemical NLWs that are environmentally acceptable and used for defensive and protection purposes only; (3) investigate thoroughly which additional technologies and concepts should be pursued in collaboration with the US or other NATO Allies, to ensure affordable participation by Canada; (4) enlist Canadian universities to contribute their R&D expertise on chemical counter-materiel NLWs: (5) make use of the Biological and Chemical Defence Review Committee to ensure that all activities within these programs are defensive in nature, with no threat to public safety or the environment.

3.4 Radio Frequency Weapons and Directed Energy Weapons (Annex D)

High Power Microwave Weapons (HPMWs) form a sub-set of directed energy weapons and are used to damage or destroy enemy equipment, facilities (and possibly personnel), by irradiating them with electromagnetic waves of high intensity, from a distant or standoff location. Primarily, HPMWs are intended to cause a function "kill" of the target attacked by disturbing, upsetting or damaging the target's electronics by HPM irradiation, and are thus most useful in disabling rather than destroying "intelligent systems". In such applications, lower energies are needed to disable, rather than destroy equipment (such as missiles, vehicles or communications facilities). Since microwaves are part of the electromagnetic spectrum, they travel at the speed of light, a speed that is many orders of magnitude greater than the fastest shell or missile. This fact makes HPMWs operationally useful since it provides exceptionally short reaction times in self-defence situations, for example, against incoming cruise missiles once the latter have been detected by radar or by other means. Adding a capability such as electronic beam steering by means of phased- array antennas, a HPMW could defend against a concerted attack by many missiles approaching from a given direction or sector.

Numerous self-protection and attack scenarios exist in the defence context, and offer a sense of the possibilities, advantages and limitations of HPMWs in typical situations, as opposed to predicting the characteristics and capabilities of future weapon systems. Scenarios of self-protection include: large ships against incoming cruise missiles; large aircraft against surface-to-air and anti-aircraft missiles; fighter aircraft against attacking missiles; and military units against attacks by 'intelligent" ammunition. In the same way, attack scenarios include: suppression of enemy air defence and C3I facilities; disablement of enemy low-earth orbit satellites and other high-value targets; dispersion of crowds, rioters and in counter-terrorist situations using non-lethal HPMWs; and disablement of an enemy's domestic critical infrastructure, transportation and communications systems and its civilian defences.

While countries such as the US, France, UK and Russia are the main players in the field of HPMWs, DRDC is Canada's only player in this field and the current level of effort is minimal, because of the anticipated high development costs. Sharing of HPM technology between minor players, such as Canada, and the major international players is also minimal. Yet the interest for HPMWs from CF clients is growing, as the number and diversity of potential applications (for both self-protection and attack purposes) increases.

The potential R&D opportunities identified by the author are: (1) exchange information among the CF services (land, maritime, air) and coordinate all CF requirements with the DRDC R&D programs' ability to meet those requirements; (2) develop a coordinated strategic direction and research areas in which DRDC can play a role; (3) secure DRDC funds and other resources to upgrade the existing facilities to a position where they can play a significant role in exploiting HPM technology for CF purposes.

3.5 Acoustic Weapons (Annex E)

Acoustic weapons are devices that are used to aim mechanical energy at a target using sound waves and air pressure as carriers. While the use of sound as a weapon of psychological warfare in historical battles has been written about since antiquity, verification is impossible. More recently, sound in the audible range has been used in psychological warfare operations creating a variety of effects, depending on the frequency/wavelength and intensity of the sound: hearing interference, performance degradation, pain, temporary hearing loss and tissue damage. In crowd control operations, sound "blasters" have been used to deter or repel people, and are commercially available to police and military forces.

Although generally unverifiable and irreproducible, claims abound about the incapacitating nature of "infrasound", the inaudible region below the audible. "Infrasound" or low frequency acoustic oscillations can theoretically be used to induce resonant vibrations, matched to the resonant or natural frequency of the target body's organs or cavities. Weaponizing such devices is difficult because infrasound is dispersive, non-directional, limited in range, and dependent on a large number of characteristics of the target (mass, size, mechanical properties of internal organs, age, gender, and degree of fitness). Physically massive and bulky, "infrasound" weapons (given their current state of technological development) would likely be uncontrollable and unpredictable, possibly causing as much disruption to one's own forces as to the enemies'. Sound intensity (persistent for about ten seconds), meanwhile, has more demonstrable physiological effects in humans, from irritation (at the modest power levels), to sickness/headaches, to loss of bodily functions, and finally to total incapacitation (at the very highest power levels). "Ultrasound", in the frequency range higher than the audible, can be formed into beams, and at low power is used in a variety of procedures: non-destructive evaluation of materials and non-invasive medical/dental investigations and therapies. At high power needed for weaponization, propagation becomes non-linear, and is highly dependent on atmospheric conditions, limiting the effective range and the ability to control the effective power level at the target. Although claims have been made about the psychological and skin surface physiological effects of "ultrasound" weapons, it is generally believed, in the scientific community, that such weapons do not affect the target's psychological behaviour beyond the physiological, aural discomfort.

Early R&D indicates that Vortex ring generators may be able to deliver low frequency periodic shock waves, which combined with high noise levels, could be used as a crowd control device. Single burst vortex ring are able to knock targets off balance at short ranges, without doing any long-term harm. Vortex rings could also transport irritants (gas or particulates) to enhance crowd control.

The opportunities for weaponization of acoustic devices (for defence applications) seem limited at present, and despite some claims in the literature the technology does not seem to have passed the level of annoying/repelling people through the use of use of mere sound intensity. Many countries have reduced the amount of their R&D effort in this direction.

Pyrotechnic device known as stun-grenades or flash-bang grenades have been developed and are available in the market. However, little has been done to characterize their effects on people.

The potential R&D opportunities identified by the author are: (1) maintain a technology watch on the general topic (2) characterize the effects of pyrotechnic stun and flash-bang grenades.

3.6 Non-lethal Weapon Research and Development for Defence R&D Canada (Annex F)

This paper, from which the main body of this report drew heavily, describes the general status, as of November 2003, of CF NLW policy, doctrine and equipment requirements and the various NLW international studies in which DRDC or the CF have been involved. The paper identifies the key S&T challenges to NLW R&D as being the scarcity of scientifically gathered data on NLW effects, the lack of modeling and simulation tools to assess NLW operational effectiveness and the counter-measures to the weaponization of the technologies found in the NLW taxonomy. The author recommends that given the increased number of peace support operations DRDC should initiate R&D in blunt trauma, electrical energy and chemical based NLWs to assess their effects and operational effectiveness.

3.7 Non-Lethal Weapons Effects Evaluation Methodology (Annex G)

This paper draws upon the work of a NATO Studies, Analysis and Simulation (SAS) Study Team (of which DRDC was a participant), developed a NLW Effectiveness Evaluation Framework. Building on the NATO NLW Technology Taxonomy (electromagnetic, chemical, acoustic, mechanical/kinetic, ancillary), the methodology so developed from this study outlines several scenarios (each of which includes the environmental factors which could affect the performance of the NLW; the physical weapon characteristics, such as size mass, power consumption, calibre, frequency, etc.; and the measure of performance, such as the terminal momentum of a baton round, the optical intensity of a flash-bang grenade, the field strength of a directed energy weapon, etc.). Therefore, the same weapon, under different environmental conditions, will produce different measures of performance. The formalism of the methodology is developed, through various stages: measure of response; measure of system effectiveness; and measure of operational effectiveness.

Evaluation models are finally developed, which relate a specific model to a model function (target response characteristics, measure of operational effectiveness) to a functional area (anti-personnel and/or anti-materiel). DRDC has some expertise in anti-personnel kinetic NLWs, arising from earlier work on models developed to study Behind Armour Blunt Trauma, which could be adapted to characterize the effects of kinetic NLWs. The major conclusions, using the methodology developed in the study, are: all tasks identified in scenario analyses can be described in terms of a few target responses, which provide one of the links to determine system effectiveness; the target response factors are related to different phases of a mission, operation or scenario; complex weapon measures of performance can be converted into target responses using appropriate mathematical transfer functions; the absence of target response data is a significant inhibitor to the implementation of this methodology.

The potential R&D opportunity identified by the author is to participate in the follow-on study and obtain physiological and psychological target effects data to test the effects evaluation methodology developed in the former study.

4 Legal and Ethical Constraints

There are numerous legal and ethical constraints related to the use (in war or in Peace Support Operations) of NLWs. International treaties and conventions such as the Geneva Conventions,[4] the Chemical Weapon Convention[5] and the various other laws grouped under the Law of Armed Conflict all restrict the operational use of certain weapons in peace support and war situations. Rules of Engagement can clarify the use of non-lethal force for deployed soldiers in specific scenarios but may also restrict their use based upon the particular operational mission.

The legal and ethical suitability of the non-lethal application of technologies is complicated by the fact that many of the international laws and protocols were developed at a time when wars were generally fought between states using uniformed forces abiding by some recognized code of conduct. Now military forces are conducting peace support operations where a state of declared war does not exist even though one is being fought, non-state armed organizations are involved and many non-combatants are present. Furthermore, certain technological advances were not foreseen or anticipated when these international agreements were drafted. Some technology areas such as chemicals and electrical power have progressed to the point where non-lethal applications, that can save life, are possible. While R&D cannot, by itself, resolve these legal and ethical issues, it can assist in informing the debate, by providing sound scientific data on NLW effects and through modelling and simulation on their operational effectiveness.

5 Evolving Military NLW Requirements

Military capability needs continually evolve in response to changing military missions and the operational environment. The importance of a NLW capability is an excellent example of this where their deployment is becoming a common feature of Peace Support Operations. The CF recognizes that NLWs expand the options open to a commander when the use of lethal force is either prohibited or inappropriate. The CF has approved doctrine and training for the acquisition and use of NLWs in Crowd Confrontation Operations.[6] Each of the environments has addressed its own NLW needs to varying degrees. Not surprisingly, the Canadian Land Force has the most mature statement of the desired NLW capabilities likely because most probable NLW scenarios for the CF tend to be urban and land-based. In fact, the capabilities described in its concepts and doctrine have gone beyond mere crowd confrontation operations. It is evident in urban wargames that NLWs provide a precise effect on a target as well as minimizing collateral damage and non-combatant casualties.[7]

Unfortunately, NLW R&D has not kept pace with the rise in NLW requirements. From a science and technology perspective, neither the psychological nor physiological response of targeted individuals or groups exposed to NLW technologies is well understood, either in the short or long term, or time taken for recovery. The acquisition of actual human response data can generally be acquired by carrying out controlled “dose-response” experiments on human subjects, provided that ethical, legal and human rights' constraints are respected. Historically, data has been acquired from anecdotal evidence, from crowd confrontation experience, from police/military response to insurgencies, from military/special forces response to terrorists/hostage takers, and from similar operations against civilian demonstrators and paramilitary groups. Consequently, it is difficult for military staffs and commanders to make NLW procurement, training and deployment decisions with the same degree of certainty normally associated with lethal weapons.

6 R&D Challenges

While either NATO or The Technology Cooperation Program (TTCP) has conducted at least ten studies on the effects and effectiveness of NLWs, DRDC participated in only a few. These studies are an indication of the large international effort being devoted to NLW R&D. However, these studies have also shown that many countries are reluctant to share any NLW data that they may have collected unless they receive related and original information of comparable S&T value in return. It is therefore in the CF and DND interest for DRDC to conduct its own NLW R&D. This R&D should be directed towards the main S&T obstacles facing NLW R&D. The international studies suggest that these S&T obstacles are:

- Scarcity of NLW Effects Data. There is a scarcity of well documented human and materiel target response data to the various NLW technologies. While there are many anecdotal references to NLW effects in after-action reports, the scientific values of these observations and conclusions are difficult to validate. Moreover, the development and potential application of non-lethal/directed energy technologies is outpacing the understanding of their effects. In particular, the human physiological and psychological effects of many NLW technologies, in both the short term and long term, are not well understood even by countries with large NLW programs. The effects of the various non-lethal technologies must be understood as a first step in NLW R&D; otherwise, it is difficult to identify the key areas that can be reasonably exploited to meet the user's requirements, especially as the numbers and complexities of military operations increase.

- NLW Effects Data Requirements. This situation is compounded by the lack of standardized research metrics and protocols to collect the data. This poses the question of how specific experiments are to be conducted with the requisite scientific rigor to collect the target response data and, critically, how the correct non-lethal dosage can be calculated. As well, the lack of standardization in the data collection and in the research protocols, both of which are considered essential, complicates collaboration and transfer of existing data both within and between nations.

- Operational Effectiveness Difficult to Assess. Even when the effects of NLW technologies are known, modeling and simulation tools are needed to assess NLW operational effectiveness in realistic employment scenarios and to analyze the cost/benefit ratio of the R&D investment to the CF. These tools have not been developed, in part because the effects data needed to populate and exercise them have not been collected. A current modelling and simulation tool cannot be modified, nor a new one created unless an effects database exists that shows the interaction of the NLW with the target. International studies have also recognized the lack of a NLW assessment tool as a key deficiency facing NLW R&D and operational analysis.

- NLW Force Protection Measures. The right to self-defence is never denied and counter-measures against non-lethal attacks may become an important force protection measure. The requirement may be particularly acute where the opposing force's NLW inventory is more extensive or advanced than that of the CF. Some adversaries may not feel constrained by international law and so develop chemical and biological NLWs that other states may consider illegal or prohibited. For instance, there are readily available industrial and pharmaceutical chemicals that could be turned into chemical NLWs. This is particularly alarming if the physical incapacitation or behavioural change and subsequent treatment are unknown. The international studies referred to above did not consider counter-measures against non-lethal chemical or against any other technologies in the NLW Technology Taxonomy. The development of NLW counter-measures for the CF, which has many soldier and vehicle protection systems different from our allies, is a national responsibility. Selected R&D should therefore be conducted to devise prudent force protection or counter-measures for the CF, against NLWs.

7 Leveraging Current DRDC NLW R&D Expertise

Over the past decade, DRDC has maintained a technology watch through NATO and TTCP, and conducted limited NLW work. Despite this modest approach, DRDC, including the Operational Research Division, possesses some expertise in several related NLW technology areas. The knowledge gained in blunt trauma, operational medicine, directed energy and the human response to chemical hazards are perhaps the most obvious examples. Scientists in all the DRDC Research Centres have access to data sets that could be relevant to specific non-lethal effects and force protection counter-measures. The scientific skills involved in some of these areas are undoubtedly more transferable to NLW applications than others, and time will be needed for all those transferring their skills to become familiar with the technological issues and barriers facing NLW R&D.

Leveraging this expertise requires that the scientists who possess skills applicable to NLW R&D devote their time and effort away from lethal or human performance and towards applications. The direction in which the expertise is leveraged should be based upon the particular NLW application's scientific value, enhanced operational effectiveness and timely delivery. The focus of this work should be on the key technical challenges of gathering effects data, defining data requirements, operational effectiveness assessment and counter-measures, identified earlier. Full use of international cooperative programs would enhance DRDC work, by learning the lessons of success and failure from our Allies, gaining their insights on the rationale behind the technical challenges facing NLW R&D, and avoiding duplication of effort.

The technical papers attached as annexes are examples of leveraging present DRDC expertise in that they recommend potential NLW R&D in specific scientific areas. The prerequisite for such work of this type is understanding the underlying R&D challenges and determining a methodology to scientifically collect meaningful target effects data (i.e. physiological and psychological effects, operational effectiveness, modeling and simulation and counter-measures). This will apply for each of the technology areas. This is a tremendous amount of work, which will at the very least require prioritization and phasing. Although this is a difficult issue of competing priorities and limited resources, it can be done as illustrated by the newly started Advanced Research Program project on NLW research protocols which spans three technology areas (i.e. physiological effects of selected blunt trauma, directed energy and acoustic NLWs).

8 Conclusions

This study has drawn the following conclusions:

- The evolving operational environment since the end of the Cold War have made NLWs a pressing military capability requirement;
- Developments in many technology areas have advanced to a point where the potential for many NLW applications can now be seen;
- International studies have indicated that the major technological challenges facing NLW R&D are: the scarcity of well-documented target response data to the various NLW technologies; NLW effects data requirements; the lack of modelling and simulation tools to assess the operational effectiveness; and, NLW counter-measures.
- DRDC expertise in lethal weapon, protective measures and human performance R&D is applicable to many areas of the NLW Technology Taxonomy; and
- Legal and ethical constraints must be respected in NLW R&D.

9 Recommendations

This study recommends that:

a. DRDC conduct active R&D in selected NLW technology areas;
b. The objectives of this NLW R&D are to:
   i. assess NLW target effects;
   ii. define standardized effects data requirements;
   iii. recommend modeling and simulation tools to assess operational effectiveness; and
   iv. identify counter-measures.

An R&D program that addresses these objectives will allow DRDC to provide the CF with science and technology knowledge on the effects, operational effectiveness and counter-measures of selected, emerging NLW technologies.

10 References

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7. Future Army Experiment, Operations in the Urban Battlespace, Fort Frontenac, May 2002

11 Annexes

Annex A. Kinetic-Energy Non-Lethal Weapons

Annex B. Laser-Based Directed Energy Weapons

Annex C. Chemical Counter-Materiel Non-Lethal Weapons

Annex D. Radio Frequency Weapons and Directed Energy Weapons

Annex E. Acoustic Weapons

Annex F. Non-Lethal Weapons Research and Development for Defence R&D Canada

Annex G. Non-Lethal Weapons Effects Evaluation Methodology

Annex H. Non-Lethal Weapon Technology Taxonomy

Annex A. Kinetic-Energy Non-Lethal Weapons

By

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DRDC Valcartier

April 2004

1 Technology Description

Kinetic-energy non-lethal weapons (KENLWs) have been in use for many years. The working principle of these weapons is to inflict pain on the target by impacting it with a hard object. The object can be a projectile (e.g. rubber bullet, baton round, etc.) or a hand-held stick (e.g. truncheon). This section will address mostly projectile-type KENLWs. The efficiency of these weapons is influenced by many factors that will be discussed in the following paragraphs.

1.1 Impactor Type

Current KENLWs are generally available in 37 and 40-mm calibres, and 12-gauge cartridges. A 9-mm rubber bullet also exists. The size, weight, shape and material used to build the impactor can vary considerably, as shown in Refs. [1, 2]. These variables are summarized in the following paragraphs. In general, KENLWs are used either as a point or a crowd control. Point control KENLWs are designed to neutralize one person at a time; thus, one projectile is generally used to do so. Crowd control KENLWs (or area weapons) are designed to neutralize many people with one shot, as many projectiles are fired at once.

The materials used in KENLWs are generally made of either foam, plastic, rubber, Styrofoam, lead, steel, silica or wood. Silica, lead and steel projectiles are usually launched many at a time in a textile pad to prevent penetration of the projectile in the target. They are usually called "beanbags" (e.g., ALS Technologies 12-Gauge Power Punch Ballistic Bag). The hardness of the material of which the impactor is made greatly affects its efficiency and the range varies from 55 to 90 Durometer "A" scale. Some are made of two materials; the base is made of plastic to add weight and flight stability, while the nose is made of foam to attenuate the impact (e.g. 40-mm NL Point Fire Sponge Grenade, M1006 developed by USARL). Some projectiles are used to release a dyeing agent. They consist of a thin-skinned plastic canister containing a liquid or a powder. Some of these projectiles are optimized only to release the agent, while other types are designed both to create blunt trauma and release the agent.

The shape of the projectile will influence its external ballistics and thus the precision of the weapon as well as its capacity to cause a blunt impact on the target. The basic shapes used are: cylinders, spheres and pellets of different sizes. There are also more exotic shapes like bomblets (e.g. the 12-gauge Fin Stabilized Point NL cartridge) and "beanbags". Some have an airfoil shape, while others are drag- or fin-stabilized in order to be more accurate. Beanbags usually have rectangular or circular shapes. The different projectiles available can also vary considerably in length.

The weights of the projectiles vary from tens of grams to 200 grams. The smaller ones are launched in batches up to 300 at a time, either in a pad or in free flight, while the larger ones are launched alone. The free-flight ones are meant to be area weapons.

1.2 Impactor Accuracy and Range to Target

The accuracy and range of a KENLW are controlled by its muzzle velocity, shape, weight and stabilization mechanism. Point control KENLWs are usually more precise than crowd control ones. The initial velocity of KENLWs is usually from 60 to 320 m/s. Reference [1] describes a series of tests, which were performed on KENLWs; their accuracy was measured at 21 feet (6.4 m) and 75 feet (23 m). At 21 feet, the accuracy varied from 2.5 to 47 inches, while at 75 feet, it ranged from 5 to 30 inches. At 75 feet, some rounds could not hit the target because they were too inaccurate. The accuracy was measured as well as the diameter including the dispersion of 5 rounds. Some designs were found to be more stable than others. Fin- and drag-stabilized, as well as pads, are usually the most accurate ones.

KENLWs usually have a range of efficiency that is specified by the manufacturer. The effective range depends on the muzzle velocity of the projectile, its drag characteristics and dispersion. The effective range specified by the manufacturer [2] is generally wider than that measured in [1]. One should also note that the maximum range of these munitions considerably exceeds the effective range. There is no standard, test method or definition of an effective range, except that it is observed when a given ammunition is effective without resulting in serious injuries or death [1], without specifying how the lethality or injury potential is measured. Thus, a minimum and a maximum range outside which no target should be engaged characterize the effective range. The minimum range is preferred to prevent accidental death of the target since the kinetic energy of the projectile is too high. It is usually around 10 meters, although it can vary from 3 to 20 meters. The maximum range is set because of the inaccuracy of the projectile at longer ranges or because the projectile does not have enough velocity to inflict significant pain to the target. The KENLW range is at its maximum around 80 meters, although most part of it is effectively shorter (50 metres or less).

1.3 Impactor Momentum

To give an idea of the impact momentum provided by KENLW, in Ref. [1], the momentum of 103 different projectiles has been measured at 21 and 75 feet. For KENLWs impacts at 21 feet, the measured momentum ranged from 0.406 Ns up to 11 Ns. At 75 feet, the measured momentum ranged from 0.56 Ns to 8.21 Ns. For comparison purposes, a 141-gram baseball pitched at 30 m/s provides a momentum of 4.3 Ns.

1.4 Effects on Target

The effects on target are numerous, although the intended effect is to inflict pain by causing a blunt impact. First, it should be said that the level of pain, and thus the incapacitation of the target as a function of the impact condition, cannot be evaluated on the basis of the current knowledge from aircraft, automotive and sport industries, and military research in biomechanics. In the aircraft and automotive industries, the impacts usually involve large areas of the body and the loading rates are usually longer than for KENLW. The sport industry and military research results can lead to a gross evaluation of injury levels and death, but the level of uncertainty is high because many variables are involved and the test data in that field are sparse.

The following variables will influence the target response to a KENLW impact: impact location, velocity and mass, health condition, age and protection of the target.

Impact velocity and mass will influence the intensity of the results. Depending on the impact location, the physical body response will vary since different anatomical structures would be loaded. Hence, the physiological response of the person will be different. For example, a thoracic impact might result in a series of different physical responses ranging from simple contusion to more permanent damage like rib fracture, lung haemorrhage, to potentially deadly consequences such as ventricular fibrillation and commotio cordis (heart commotion) [3, 4, 5]. Similarly, an abdominal impact can result in internal haemorrhage with sometimes fatal consequences [6]. For head impact, the consequences can range from simple skin contusion to skull fracture or brain contusion with loss of consciousness to brain commotion [7]. Furthermore, impacts to the face can result in facial fracture or permanent blindness. In general, the head, neck and torso areas are the most likely to be injured due to impacts.

A previous evaluation of possible injuries that can be inflicted to targets assumes that the projectile hits the target without penetrating it. Cases of rubber bullets and beanbags that penetrated the body sometimes quite deeply [8] have been reported. Also, for some KENLW ammunition, the attitude of the projectile at the impact at certain velocities can result in the penetration of the body.

Even more difficult to assess is the psychological response of a target to such impacts. Medical literature (both civilian and military) reports numerous cases of unexpected responses.

Health condition and age of the target also influence its response. For example, in the US commotio cordis data bank, in 140 cases over 5 years, the average age is 14 years with 78% being less than 18 years old [5]. Most of these accidents occurred while playing baseball. Thus, young people are vulnerable to impacts very similar to those KENLWs can provide. In the UK, it is reported that for the 17 deaths that occurred by using KENLWs, 7 were children [9, 10, 11, 12]. For older people, lower bone mass density makes their body structure more brittle, and thus more fragile to high rate impacts.

The protection (either intentional or not) worn by the target will influence its response to KENLW. During demonstrations, it has become quite common to see professional troublemakers wearing motorcycle or hockey helmets, hockey pads and baseball or hockey plastrons.

Although 17 deaths were reported in the UK between 1973 and 1997, it is estimated that over 55000 baton rounds were fired by the Royal Ulster Constabulary forces [11]. A closer look at those accidents reveals that they are mostly the consequence of a misuse of the weapon. Either the target was too close, or the projectile hit the target on the head, in the face or on the thorax. But this is only the tip of the iceberg, since the number and severity of the injuries inflicted by those 55000 baton rounds on persons are not known. Since 1989, when the UK put in service a new baton round, no lethal impacts have been reported yet.

For all these reasons, KENLW must be used with care. Personnel should be well trained to prevent injuries and even death of the target. A clear doctrine on how and where to use these weapons must be stated. Furthermore, it is essential to evaluate their effects to prevent unnecessary injuries or deaths. A better understanding of the target response under the impact of these munitions can provide an answer. Hence, it will be possible to develop standards and test methods to evaluate the effects.

2 State-of-the-Art in Kinetic Energy NLW

2.1 International Efforts

2.1.1 France

In France, a considerable amount of effort has been devoted to understand the effects of thoracic and head behind-armour blunt trauma (BABT). Through the use of biological and numerical models, the French have improved knowledge of the phenomena. Most of the work has been carried out by the ETBS along with the ISL. This work has been managed by the "Service de santé des armées" of the DGA. Although the efforts during the last years were aimed mostly at understanding BABT, the technology and know-how was recently shifted towards KENLW. For many years, France has been working on anaesthetized biological models in order to monitor their physiological reactions and observe the extent of injuries caused by BABT. Different specialized measurement techniques have been used to evaluate the physical and physiological reactions of the model.

Recently (2003), France has evaluated flash-ball rounds on a biological model. A larger project to develop and test more KENLW as well as other types of NLW is currently being defined. Canada has a Specific Arrangement (SA-22) on thoracic impacts related to BABT. That SA can be extended to blunt trauma effects of KENLW up to a certain point, but the best solution would be to implement a new SA. As part of that new SA, Canada would be granted access to France's biological model test results as well as to the development of countermeasures. Preliminary discussions have resulted in a lot of interest from both parties.

2.1.2 United Kingdom

For over a decade, the UK has been working on the problem of thoracic blunt trauma. Pioneer work has been carried out in that field with tests of eviscerated biological models. Once again, the problem under investigation is BABT although a first test series involved the use of a KENLW (140-g baton round). Focus is now being shifted towards the use of anaesthetized biological models in order to monitor the physiological reactions of the model under impacts and observe the extent of injuries caused by BABT. Specialized measurement techniques are being developed by the UK to evaluate the physical and physiological reactions of the model. A KENLW program using biological models is still underway at DSTL Porton Down, but the author is not aware of any future program specifically on KENLW. The UK also conducts extensive R&D on the thoracic BABT problem. Data were exchanged with the UK through different international forums.

2.1.3 USA

The USA has a quite extensive program on NLW and specifically on KENLWs. They have also carried out extensive research in BABT. The two parts of the program will be discussed here.

JNLWD (Joint Non-Lethal Weapons Directorate), in Quantico, VA runs the US NLW program. ARDEC has been awarded most R&D work on KENLWs planned for that program in Picatinny Arsenal, NJ. The US Army is currently using a non-lethal capability set which includes point and crowd control KENLWs as well as a non-lethal version of the Claymore mine. ARDEC is also developing KENLWs within that program. It includes the development of KENLW ammunition such as 40-mm MK19 NL ammunition short range (up to 50 m) as well as a long-range version (up to 1000 m). Up to now, the short-range versions have been developed with multiple rubber pellets as payload. The long-range version is being developed within the OICW program. The USA also performs evaluations of protective equipment and anti-riot gear. In terms of human effects, the US program is evaluated by the HECOE (Human Effects Center of Excellence), at Brooks AFB, TX. This Center specializes in the evaluation of the effects on the target, both effectiveness and risk to the target's health and safety, and is involved in the evaluation of the options taken by the NLW designers and processing of the ammunition.

In recent years, considerable effort has been devoted to evaluate the effects of BABT in the USA; namely, the University of Virginia Car Crash Laboratories have been sponsored by the Natick Soldier Center to conduct BABT head impact studies, and more recently, thorax impact studies with biological samples. All these data were shared with Canada through international forums. Furthermore, USMRMC, which is the main organization of the HECOE, is currently conducting R&D activities on thoracic BABT.

2.2 National Efforts

2.2.1 DRDC Valcartier

DRDC Valcartier was sponsored by DLR 5 to perform R&D activities on BABT effects and establish test methods to evaluate protective equipment. This resulted in the development of a head and thorax model.

The head model was validated through international collaboration and is now considered to become part of the NIJ (National Institute of Justice) standard for ballistic helmets. It uses a specially instrumented Hybrid III head to measure the head acceleration and impact force on the skull resulting from the deformation of a ballistic helmet under impact. The model makes it possible to predict the resulting skull fracture. Also, a numerical model of the head, including the skull and the brain, has been developed specifically to evaluate head BABT effects.

The thoracic model simulated the thoracic wall dynamic under impact. It was validated using 140-g baton rounds at low velocities (i.e. loadings similar to KENLW rounds), but it needs to be validated for the BABT problem. Also, the injury criteria related to BABT (either from a KENLW or the BABT side) are still being discussed in international forums.

Evaluations of the current equipment and protection concepts have been performed using these two models. In terms of KENLW development, no work has been carried out, although related work on the protection against BABT effects can be applied.

2.2.2 DRDC Toronto

Although no effort is currently being devoted to KENLW, DRDC Toronto possesses an expertise in the medical aspect of blunt trauma and on animal studies that can be used in the development or the understanding of the effects of these weapons. Furthermore, DRDC Toronto possesses an expertise in psychology for the CF.

2.2.3 Industry/universities

In Canada, industries involved in personnel ballistic protection, anti-riot equipment and ammunition development have dedicated R&D effort that can be used in the development of KENLW ammunition or protection concepts for the CF soldiers. Some universities specialize in the shock/impact attenuation and ballistic protection problems. Table 1 presents a non-exhaustive list of companies and universities of interest.

Table 1

Company/university name	Field of interest
Med-Eng Systems	Anti-bomb and anti-riot suits
Mawashi	Anti-riot suits and martial arts protection ensembles
Aceram Technologies	Ballistic plates
CPC	Ballistic plates
PSP	Ballistic protection equipment and safety devices
SNC TEC	Ammunition development
University of Waterloo	Ballistic armour design, high strain rate characterization of materials, numerical modelling of impacts, impact attenuation materials

2.3 Technology gaps

For KENLW, the recognized gaps are:

- Evaluation of the lethality and injury potential of the munitions. As mentioned in the technology description of this chapter, many factors will influence the lethality and injury potential of these weapons. If these problems are not solved, it will not be possible to ensure that the safety of munitions and goals (of KENLWs) is reached.

- Evaluation of the effectiveness of the munitions. Ways to evaluate if the munitions do or do not incapacitate and how much they do incapacitate is of primary importance. Tests are usually conducted on anaesthetized animals. This prevents the evaluation of the behavioural and psychological effects of these weapons, which is the core of the effectiveness evaluation. Using a conscious animal would raise ethical issues in many countries.
- Test standards must be specified to evaluate the effectiveness of KENLWs. Currently, it seems that each manufacturer has its own standards. This will result in more comparable performance estimations and simplify the selection of KENLWs.
- Longer effective range and improved accuracy of KENLWs can lead to a wider use of these types of weapons and make them safer.
- Short-range lethality of KENLWs is also a problem that needs to be solved to make them safer.

3 Military client perspective

The CF defines NLW as: "Weapons, munitions, and devices that are explicitly designed and primarily employed so as to incapacitate personnel or materiel, while minimizing fatalities, permanent injury to personnel and undesired damage to property and the environment. "

Based of the epidemiology and on what we know about blunt trauma, it is quite clear that any selected KENLW must:

- Be accompanied with clear instructions on how to use them and the proper training to ensure that the weapon is not misused.
- Be adequately evaluated so that the performance of the weapon is well known.
- Be limited to accurate weapons. Thus point control weapons are favoured.
- Use a range of effects, since there is no multi-purpose KENLW.

4 Ethical Considerations

4.1 Use of KENLW

Since they are already being used around the world, KENLW clearly cause a lot of concern to government, police/military forces and health professionals. The lethal and injurious effects of these weapons are known to some extent and they are discussed by professionals and in the medias. Since no one can unequivocally guarantee that no deaths or permanent injuries will result from these weapons, their use must be strictly controlled. The concepts of minimal force, proportionality of force and collateral damage must be taken into account when KENLW are used.

4.2 R&D ethical considerations

Because of the lethal and injury potential of KENLW, the use of human subjects is not permitted a priori. Nevertheless, protocols where human subjects can be used can be designed. Medical, pharmaceutical and human physiology research do use human subjects on a day-to-day basis for their experiments. The use of animals to evaluate the physical, physiological and behavioural effects of KENLW is strictly controlled within DRDC and throughout the country. Similar laws exist in other countries. Mostly, in physical and physiological evaluations, anaesthetized animals will be used. But in order to evaluate behavioural effects on animals, they must be conscious and active. Whether it is for humans or animals this type of test would create a certain degree of ethical discomfort in many countries.

5 Pertinent expertise within DRDC

DRDC Valcartier has an expertise in the development of biofidelic tools and test methods for blunt trauma effects. Similarly, for KENLW ammunition development, DRDC Valcartier has also an expertise in launch dynamics, external ballistics and terminal ballistics. DRDC Toronto has an expertise in the medical aspects of blunt trauma and animal studies. DRDC Toronto has also considerable expertise in human physiology and psychology, which can be helpful in understanding the behavioural aspects of KENLW. Finally, DRDC Suffield has also considerable expertise in the evaluation of weapon effects on animals, more specifically with NBC weapons.

6 Recommendations

KENLWs are widely used around the world. Although some important technical information is known about these weapons, much more is needed to fully understand how KENLWs can incapacitate, and more importantly how to design them so that they will not kill or severely injure the targets. Thus, the recommendations can be split out into four steps:

- The first step is to perform R&D on the physiological/psychological effects and resulting behaviour of the target. This would then make it possible to evaluate the performance of KENLW as a function of that aspect;
- The second step is to carry on R&D on the injury mechanisms and criteria of blunt trauma when impacts occur to the head, neck, thorax or abdomen. This needs to be done since the data available cover only a few of the numerous possible scenarios during a riot. For example, impacts to the face, to the eyes, in the abdomen, in the pelvic area and on the thorax other than those on the sternum have never been studied. This will provide guidelines for the design of KENLW ammunition that will cause less injury;
- The third step is to develop test methods for evaluating, in a scientific way, the technical performance and, in a limited way, the injury potential of the weapons, so that the information is comparable from one laboratory to another. The injury potential can be determined by using the current knowledge acquired in BABT research and by adapting the current BABT physical models to the KENLW issue. As more data become available in steps 1) and 2), the test methods can be upgraded;
- The fourth step is to develop a KENLW that will be really non-lethal from the muzzle up to 100 metres with accuracy.

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Annex B. Laser-Based Directed Energy Weapons

By

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October 2003

1 Technology Description

Lasers have proliferated on the battlefield during the last 30 years. Initially used as a rangefinder in some weapon systems, a laser beam is also used as a target designator to guide a missile (also smart bombs, gun shells or rockets) to the target. In such an approach, a coded laser beam is projected in the direction of a target and a laser target seeker mounted onboard the missile detects and tracks the laser spot until target hit. Another type of laser-based guidance missile is the laser beam rider where the operator aims at the target while the missile stays within the beam all the way to the target. Rear-facing laser sensors mounted onboard the missile determine the deviation between the beam and the missile trajectory. The deviation information is extracted through an analysis of the position data encoded in the laser beam. Due to the unique nature of the laser light, namely its coherence, monochromaticity, high degree of collimation and intensity, it could also be used as a directed energy weapon. Such weapons can be grouped in two main categories based on the desired effect at the target. The sensitivity of the target to laser light determines whether a low-energy laser (LEL) or high-energy laser (HEL) is required.

2 Low-energy laser (LEL)

LELs are essentially used as anti-eye or anti-sensor systems. As anti-eye weapons they aim at causing visual effects ranging from discomfort, glare, dazzle, flash blindness up to eye damage. Eye damage can take various forms, depending on the wavelength used. Using a wavelength not transmitted inside the eye can damage the cornea. If sufficient power is used, such a burn can make the cornea opaque and lead to very painful injuries. Lasers at longer wavelengths (above 3 μm) are particularly effective in this role. However, to generate this type of injury, at least 1 J/cm^2 has to be delivered on the subject, which requires a laser that is almost a HEL. For anti-eye purposes, it is much easier to use in-band wavelengths (visible and near-IR, 400 to 1400 nm) that are transmitted to the retina with the magnifying effect of the eye lens. As a matter of fact, the eye lens concentrates the in-band laser energy by a factor up to 100,000 times. Then the required energy levels become very low and can be easily generated at numerous wavelengths using off-the-shelf sources. Moreover, if the victim uses magnifying optics, then even more energy is collected and concentrated on the retina (for example, the irradiance on the retina is increased by a factor 49 with 7X50 mm binoculars). As a matter of fact, already fielded lasers such as laser range finder and target designators can become very effective LELs with operational ranges over 10 km. Also, it is possible to use more than one laser at the same time or wavelength agile lasers to make them more effective and resistant to countermeasures (CM). Lasers in the UV can also be used to ionize the air and so conduct electric charges to incapacitate a victim.

Another potential application of LEL is the use of a pair of ultra-violet lasers to ionize conductive paths in the air along which an electrical (high voltage) current can be directed toward a target. The overall effects are basically the same as those (uncontrollable contraction of muscle tissue) obtained with the Taser system currently used by police forces, which uses a pair of wires to carry the current to the target. However, due to the maximum permissible exposure to the UV radiation established by health safety standards, there is a limitation to the range at which the system can operate (a few tens of meters).

In their anti-sensor role, LELs aim at either knocking out enemy sensors for a certain time or purely destroy them. Here again, these sensors are most of the time fitted with optics that facilitate the task of the LEL. The most favorable situation is when the wavelength of the laser is within the operating wavelength range of the sensor. Also, multi-wavelength sources are available and more effective than single-wavelength ones because they can defeat countermeasures (CM) based of optical filtering. Finally, anti-sensor LELs can very often be used as anti-eye systems as well. Table 1 shows a series of lasers and the sensors likely to be affected (Ref. 1). In terms of dimensions, LELs can have different sizes, depending on the wavelength and the purpose of the system. Anti-eye lasers operating in the visible can be easily made portable (Fig. 1). On the other hand, if the system aims at destroying sensors at long ranges, then the laser and all its accessories may be bulky, heavy and is required to be operated from a vehicle.

Table 1
Possible anti-sensor lasers

Spectral range	Lasers	Wavelength (nm)	Sensors
Visible	Argon Nd:YAG doubled Ruby Titanium-sapphire Alexandrite	514 532 693.4 660-1160 700-815	Low-light TV Image intensifier CCD Human eyes
Near infrared	Gallium arsenide Nd:YAG FEL	904 1064 1000-10000	Image intensifier Low-light TV CCD Human eyes Thermal and IR missiles
Mid infrared	Deuterium fluoride Carbon monoxide Carbon dioxide	3000, 3800-5000 6000 10600	Thermal detectors 8000-12000

Figure 1 Example of LEL (the Dazer)

3 High-energy laser (HEL)

HELs were developed as soon as the lasers capable of delivering high energy began to be available, but their development was dramatically accelerated with the Strategic Defense Initiative (SDI) that was launched in 1983 by the US government. The main use of HELs is air defence where they aim at destroying incoming munitions or aircraft before they can accomplish their mission. In such an application, they are seen as the only solution to counter multiple simultaneous threats that would normally saturate the conventional air defence based on anti-aircraft guns and missiles. Such a HEL system must have multiple target detection and tracking abilities coupled to extremely short reaction times and very high hit probability. However, these specifications are very difficult to meet and despite the huge efforts to date, no HEL has been fielded yet. On the other hand, if the main goal of the HEL is not to destroy the target but rather to attack battlefield sensors, electro-optical systems or human eyes or skin, then it can achieve this at much longer ranges than the LEL. Finally, a HEL can also be used as a very efficient flamethrower since it can set fire to flammable objects or clothes at very long ranges.

Although a multitude of laser types exist, only a few of them (most of them being chemical lasers) can be scaled up into high energy levels; basically, carbon dioxide (CO_2, 10.6 µm), hydrogen fluoride (HF, 2.5 to 3.0 µm), deuterium fluoride (DF, 3.8 µm), chemical oxygen: iodine laser: (COIL, 1.3 µm), free-electron laser (FEL, 0.2-15 µm) and the excimer (0.2-0.4 µm). Normally, to be effective, a HEL has to produce an average beam power of several megawatts (or the equivalent in joules) during the exposure duration time. Such a high level of power is necessary (even assuming a perfect transmission through the atmosphere) due to the wide variation of the absorption of the target materials and the dependency on the wavelength. Also the reflectivity of the target material will have a major impact on the absorption. In order to penetrate and destroy targets like missiles and aircraft, these have to be irradiated with several J/ cm^2. On the other hand, optical sensors or missile noses require much less energy to damage (a few tens of joules). In their antipersonnel role, HELs have only to deliver a few J/ cm^2 to burn skin and 1 J/ cm^2 to damage the cornea.

Amongst the candidate lasers, the DF and the CO_2 are based on mature technology and transmit fairly well in the atmosphere so that they represent a realistic option for HELs. The COIL at 1.3 µm transmits very well in the atmosphere but still has to demonstrate its multi-megajoule level potential. The FEL has the major advantage of being capable of selecting a wavelength optimized for atmospheric transmission and target interaction requirements. Finally, the excimers operating in the UV band have some potential as HELs because they can emit at a few wavelengths at energies up to a few tens of thousand joules. However, the basic problem is still the atmospheric transmission and scattering. Consequently, they are more considered for applications in which the HEL would be mounted on a satellite to intercept nuclear weapons in outer space.

Independently from the types of laser technology used, HELs are inherently bulky and costly. Also, they consume a lot of power, generate a huge amount of heat and require a whole infrastructure of supporting components. Typically, HEL systems can fill a whole building or a large platform like the 747 aircraft that contains the Airborne Laser (ABL) illustrated in Fig. 2. The support infrastructure consists of a series of systems performing the following functions: power generation, cooling, target acquisition system, threat analysis and target assignment, aiming and tracking, fire control and kill assessment. Key components (other than normal laser support device) include the beam director, beam-walk mirrors to compensate beam jitter, laser beacons for sensing the atmosphere along beam path, wave-front sensing device and adaptive mirror assembly to correct for atmospheric perturbations.

Figure 2 Example of HEL (the ABL)

4 Laser interaction with the human body

The organ most vulnerable to laser radiation is the eye. Depending on the wavelength of operation of the laser (Fig. 3), the character and degree of damage can vary substantially. If it is in-band (Fig. 4), adverse laser effects are generally believed to be limited to the retina. Thus in the visible and near infrared (400 to 1400 nm), the magnification of the eye lens comes into play and the laser beam is focused onto a very small spot on the retina. The magnification effect can reach 100,000 times, so a few µJ/cm^2 are sufficient to damage the retina. The effect upon the retina of in-band lasers may vary between a temporary reaction without residual pathological change and permanent blindness. As the retinal irradiance is increased, they may cause lesions whose progress in severity up to vitreal haemorrhages of the retina with leakage of blood into the inner eyeball where the damage is permanent.

A laser operating out of band to the eye requires a higher level of density to cause irreversible damage. For instance, near-ultraviolet radiation will penetrate only as far as the lens, whereas IR radiation (10.6 µm for example) will be absorbed in the cornea. In this case, the damage threshold is more than 2000 times higher than that for the in-band laser. However, cornea burns are extremely painful and would result in immediate incapacitation of the person involved.

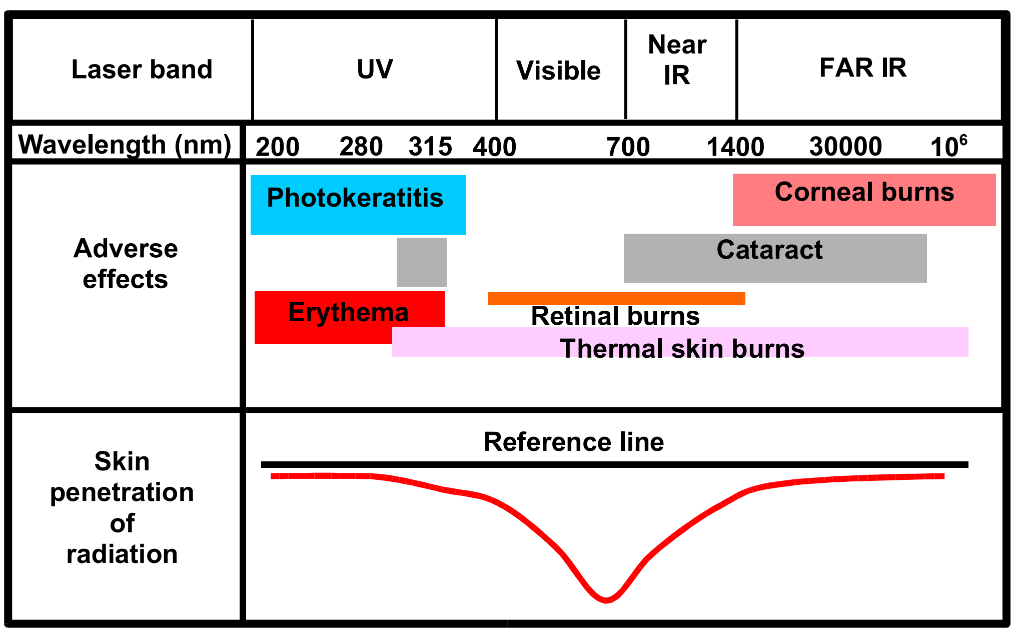

Figure 3 Adverse effects of the laser on the human body

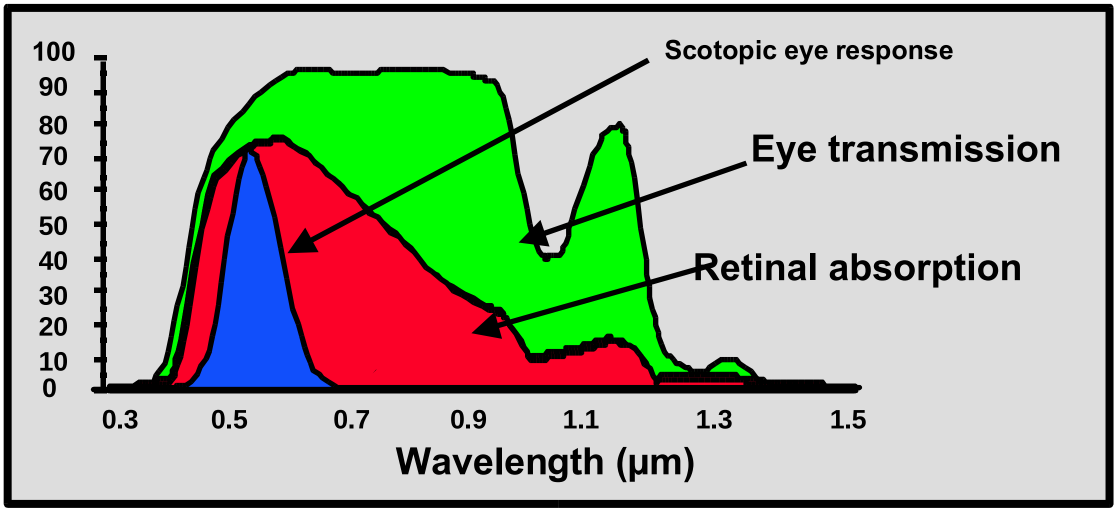

Figure 4 Eye transmission and absorption

The amount of energy necessary to lead to the different types of injuries has been determined through extensive laboratory experiments performed on animals. Such experiments revealed a statistical variation. This is expressed in terms of probability distribution for injury as a function of intra-ocular energy dose. The standard way to relate damage thresholds for all types of injuries to a single measured quantity is the Effective Dose for 50% response (ED50). ED50 represents the intra-ocular energy that produces a minimal retinal lesion in 50% of the subjects tested. Such a minimal lesion is the smallest (temporary) one that can be detected in an ophtalmoscopic examination conducted within a few hours of exposure. Table 2 shows the relation between the type of injury and the ED50 doses (for the retina) according to the classification scheme developed by Dr. John Wolfe at the Letterman Army Institute of Research (Ref. 2).

Table 2. Definition of Wolfe grade (retina)

Wolfe grade	**Physical effect**	**Duration of effect**	**Relative dose**
0	Flash blinding (visible)	Transient	1/20 of ED50
Pre-I	Minimal retinal lesion	Temporary	ED50
I	Oedema	Temporary	2 x ED50
II	Oedema and necrosis	Permanent	5 x ED50
III	Retinal hemorrhagic lesion	Permanent	10 x ED50
IV	Retinal hole and/or vitreal hemorrhagic lesion	Permanent	50 x ED50

Due to the fact that the laser threat affects mostly the eye because of the extremely low energy required, one can often forget that skin hazard also exists. It is possible to burn the skin with a laser directly or indirectly by setting fire to the clothes of nearby objects. Lasers can have several important effects to the skin. The thermal effect is the most significant one. Laser burn injuries vary from superficial reddening of the skin (12W/cm^2), through blistering (24W/cm^2) up to destruction of the entire outer layer of the skin (> 34 W/cm^2). If the exposure duration is shortened, the irradiance required is significantly increased. Laser injury thresholds for the skin are dependent on the wavelength and the pigmentation of the skin (dark skin absorbs more).

5 Advantages and disadvantages of laser weapons

One of the greatest advantages of the laser beam as a weapon is the speed at which it delivers its energy. For tactical engagements, it is like a zero time-of-flight weapon. The speed of the target will be a problem only if it is necessary to keep the beam on the same spot of a fast moving target during a relatively long period of time. Another advantage is the straight line of sight along which the energy is delivered. It is not necessary to calculate a ballistic trajectory, as it is the case with normal munitions. Consequently, laser weapons (especially LELs) do not require very costly and complex fire control systems to calculate their trajectories. Also, laser weapons are silent and can be made invisible. Finally, they do not need the huge and expensive ammunition logistic system associated with all conventional weapon systems.

Laser weapons are not perfect. For example, the laser is not capable of damaging or destroying every kind of target on the battlefield. Also, laser weapons (particularly LELs) that use an invisible beam will make it difficult for the operator to register hit and judge what effect it caused on the target. With HELs, the kill assessment may be easier because the effects are more violent. One of the main difficulties with laser weapons is their dependence on conditions within the atmosphere. Smoke and dust will also create problems. Furthermore, rain and fog can have a devastating effect on some lasers by reducing their effectiveness to almost nothing. The main effects of the atmosphere on the laser beam are absorption, scattering, turbulence and thermal blooming. Turbulence in the air generates deformations of the beam, whereas absorption and scattering will considerably shorten the maximum distance for the desired effects. Thermal blooming affects mainly HELs due to the high energy density of their laser beam, which creates plasmas in the air. These plasmas heat up the air, which causes the beam to diverge and reduces the efficiency at long ranges. Laser beams can also be detected and located by systems such as laser warning receivers. If visible lasers are used, they can be observed and the source pinpointed.

There are also protection means and countermeasures (CM) against laser weapons but there is no simple solution. The obvious protection means is the use of optical filters to block the beam. Unfortunately, the available filters do not have the necessary properties to solve the problem because they generally offer protection against a small number of fairly discrete laser wavelengths. These filters are useless against wavelength agile lasers. Wideband optical switches based on non-linear optical properties are also in development but are not providing yet sufficiently low limitation thresholds. Indirect viewing is an interesting protection means against laser weapons. For example, using thermal imagers, image intensifiers or TV cameras for observation protects the observer because only the sensitive parts of the electro-optical devices will be destroyed or blinded. Finally, smoke can be used to make target acquisition harder and attenuate the beam. On the other hand, smoke is very dependent on weather conditions such as wind and humidity.

6 Status of the laser weapon technology

6.1 International

The United States is currently the leading country in the domain of HEL laser weapons. They have three major laser weapons under development. The $1.3 billion airborne laser (ABL) program under the direction of the Air Force with Boeing as the prime contractor will mount a massive COIL laser inside a modified Boeing 747-400 aircraft. Test versions emit beams equivalent to the energy consumption of a small city. ABL is capable of generating a 40-cm laser spot at a range of 300 km. The main purpose of the system is to fly over friendly territory to strike down short- to medium-range missiles. The final goal is to have a fleet of seven ABL planes in service by 2010.

A second program, the ground-based tactical high-energy laser (THEL), is already at the advanced prototype stage. A joint program between the US and Israel, with TRW as the prime contractor, the THEL is designed to counter small short-range rockets. The THEL has already been able to knock down more than 20 rockets from as far as 12 km. The Navy is interested in variants that could be mounted on ships. The Army is working on a compact unit that could be deployed in a large truck. Versions could be ready for action by 2007.

The third laser weapon is the space-based laser or SBL. That would be mounted on satellites as protection against intercontinental missiles. A system demonstrating a missile kill from space should be ready by 2012.

There are also other smaller projects (multi-million dollars) concerning more portable versions of HELs as well as LELs. During the last decade, the US invested billions of dollars to develop and field such devices. The best-known devices are:

a. The Dazer (Allied Signal) is a man-portable device capable of firing 50 shots per minute from a 1000 shot magazine. It is currently in use with the US Special Operation Command to counter battlefield surveillance by disrupting optical and electro-optical devices.

b. The Saber 203 is a kind of laser grenade fired from a standard 40-mm M-203 grenade launcher attached to the M-16 rifle. It is deployed by the US Forces. It is designed to impair the vision of enemy soldiers.

c. The Stingray is a tactical laser system integrated into Bradley Fighting Vehicles and designed to detect and defeat threats with direct fire control systems.

d. The Outrider is a multi-faceted reconnaissance and surveillance system incorporating Stingray laser and integrated to a HMMWV wheeled vehicle for use in scout and reconnaissance missions. It is intended as a non-lethal option for low-intensity conflicts and special operations.

e. The Perseus is an optical flash 40-mm rifle grenade similar to Saber 203 developed for the Air Force. This is a grenade pulsed chemical laser putting out a flash of intense white and laser light brilliant enough to temporarily blind people and sensors.

f. The Cobra (McDonnell Douglas) is a portable rifle-like, shoulder-fired, manually operated tactical weapon intended to counter battlefield surveillance by disrupting optical and electro-optical devices.

g. The Coroner Prince was an airborne electro-optical CM system designed to detect and counter optical devices using a blue-green laser. The program was terminated in 1991.

h. The Compass Hammer is an optical CM system associated with the Coronet Prince. No other details are known.

In terms of other nations' laser weapon systems, Russia, China, Germany, the UK and Israel are known or alleged to have tactical laser programs. Russia (and former USSR) has established a very large and well-funded program to develop strategic and tactical laser weapons. The tactical laser program has progressed to where battlefield laser weapons could be deployed in the Forces. For instance, it is thought to have developed a significant number of systems similar to Stingray and Dazer that are either vehicle- mounted or man-portable devices. They are also reported to have developed the naval-based Squeezebox laser for anti-sensor or anti-personnel purposes. China has developed a laser weapon called the ZM-87 laser disturber, which was put on the open market and which is designed to impair the vision of enemy soldiers. The UK is reported to have deployed the ship-based Laser Dazzle Sight (LDS) or Outfit DEC, which is intended to produce a dazzling effect on the cockpit screen of targeted aircraft or helicopters. Outfit DEC has been configured for ground use and reportedly been fielded in tanks and armored vehicles. Germany has also been mentioned in the military literature for developing laser weapons. The best known (a HEL) is the HELEX which is a multi-megawatt CO_2 laser mounted on a tracked armored vehicle aiming at defeating low-level air attacks. Finally, it is well known that Israel is involved in at least one joint laser weapon program with the US.

6.2 National

In terms of laser-based non-lethal weapons research and development in Canada, DRDC Valcartier is the only known laboratory or industry that has an active program in the domain. Essentially, the program supports two projects: the first one, the Beam RIder Laser Localization Imaging And Neutralization Tracker (BRILLIANT), involves a dazzle-based CM while the second one, the Mid-Infrared Surveillance and Laser Engagement Demonstrator (MISLED), is aiming at dazzling IR seekers.

Basically, BRILLIANT (Fig. 5) consists of a laser detection unit, an imaging and localization device, a code breaker, a video tracker and a directed countermeasure laser. The laser detection unit is made of four heads covering each a 90° field of view for 360° coverage. Each head is designed to provide a very low detection threshold in order to acquire the LBR laser source early in the engagement sequence. Either multiple narrow-band detection channels or tunable detectors can be used to achieve the low threshold required. The photodetector then feeds high-gain preamplifiers. Both pulsed and modulated CW LBR sources are covered. The signals are then converted into digital pulses and analyzed using processing algorithms loaded in a digital signal processor (DSP). The DSP makes it possible to adjust in real time the detection threshold depending of the background radiation and minimizes the false alarm rate. The DSP also further enhances detection threshold using appropriate processing algorithms. The resultant digital pulse train then feeds a code breaker that analyzes and deciphers the information to anticipate the time of arrival of further pulses. The code breaker is capable of regenerating the input signal with sufficient phase advance to trigger the gate of an intensified CCD video camera in synchronism with the arrival of each light pulse. Normally, the gate is left open only for the duration of the laser pulses but wider gates can be used to correct for slight timing errors. When proper synchronization is achieved, the laser source appears as a white spot surrounded in a dark background. Maximum background rejection is achieved by tight gate timing but also by filtering unnecessary radiation in front of the camera lens. The images obtained are used to drive a video tracker, which controls the operation of a pan and tilt unit and makes it possible to center the target in the camera's field of view. As the tracking process is going on, the camera is gradually zoomed down to improve pointing accuracy.

Figure 5 BRILLIANT system

The countermeasure is achieved by means of an eye-safe green laser mounted on top of the camera and boresighted with its field of view. Following a lock on a target, the laser is turned on and power is gradually increased while always staying below maximum permissible exposure for the eye. Co-aligned with the green laser is another CM laser operating in a waveband compatible with the guidance beam of a missile. This laser is triggered by the code breaker and retroreflected into the optics of the firing unit. This approach serves two purposes. Firstly, it facilitates the code breaker operation as it locks on its own signal. Secondly, it enables the modification of the missile trajectory by injection of a false guidance signal.

The BRILLIANT prototype has already been evaluated in the presence of various types of LBR both on the ground and mounted onboard a ship. The demonstration was achieved at typical LBR engagement ranges and, in all cases, BRILLIANT was able to timely detect, locate, image, track and defeat LBRs. More work is currently carried out at DRDC Valcartier to further reduce the reaction time of the system and optimize the tracking and CM deployment of BRILLIANT. Also, the system has recently been miniaturized for an airborne demonstration in the UK and in Australia. BRILLIANT is now fully operational and it only requires the suitable packaging for installation onboard aircraft. Substantial investment would be needed to do so.

In parallel and in support of the BRILLIANT project, a study has been carried out to determine the effects of eye-safe laser dazzling on the aiming performance of optical aiming operators. Both naked eye and through-video camera observation tests were performed. The results showed that a significant CM effect is obtained using low-power lasers when the operators have a relatively complex task to accomplish. A break-lock was obtained in most cases. The experiments were conducted using five eye-safe laser irradiance levels and the effect was nearly constant, except at the lower end of the scale where the proportion of break-lock was slightly lower.

The MISLED project was initiated through a technology investment fund initiative. The MISLED system (Fig. 6) is not in as advanced a development state as BRILLIANT but a laser operating in the mid-IR band was developed and coupled with a gated mid-IR imager. Basically, MISLED uses the pulsed laser source to interrogate the target and then using the retroreflected signal it dazzles the sensor. Tests involving realistic targets were recently performed and look promising. The next step of development is its integration to the BRILLIANT system for a combined non-lethal detection and CM system.

Figure 6 MISLED system

6.1 Expected applications and time of availability

As seen in the previous paragraphs, the LELs are already mature and represent a real threat. They can be used in a myriad of applications mainly aiming at perturbing sensors and other E-O systems. However, they will inevitably also be used against human targets.

HEL systems are still at the advanced demonstration level and strongly supported by the US SDI program. They are highly promising but their cost is still prohibitive. The next few years will be determinant for their success.

6.2 Technology gap

There are several technologies that have to progress in support of the LEL and HEL programs. For example, a huge R&D effort (3 years) on solid-state lasers will be needed to scale up this technology to the order of 10 kW and then to 100 kW. There is a great interest for solid-state devices because they do not have to add the logistics stream that are required for chemical lasers.

Such R&D programs will result in a new breed of compact lasers that suit tactical applications requiring less power. This will also open the door to many new military applications for high-energy lasers. Moreover, there are requirements for 'white-light' lasers that would emit on wide optical bands and be almost impossible to defeat with protective means.

7 Ethical/legal considerations

The use of lasers as weapons has always been a subject of polemics and several governments have voiced their concerns about the development of lasers as anti-personnel weapons. In the nineties, in support of these initiatives, the International Committee of the Red Cross has built up a dossier of evidence that blinding is more severe and debilitating than most other wounds inflicted in war. All these efforts culminated in 1995 with the establishment and signature (by 27 countries including Canada) of a protocol (Geneva Convention Protocol) on blinding laser weapons that came into force in 1996. The US ratified the protocol only in 1999. The four articles of the protocol are the following:

Article 1

It is prohibited to employ laser weapons specially designed, as their sole combat function or as one of their combat functions, to cause permanent blindness to unenhanced vision, that is to naked eye or to the eye with corrective eyesight devices. The High Contracting Parties shall not transfer such weapons to any State or non-State entity.

Article 2

In the employment of laser systems, the High Contracting Parties shall take all feasible precautions to avoid the incidence of permanent blindness to unenhanced vision. Such precautions shall include training of the armed forces and other practical measures.

Article 3

Blinding as an incidental or collateral effect of the legitimate military employment of laser systems, including laser systems used against optical equipment, is not covered by the prohibition of this protocol.

Article 4

For the purposes of this protocol, “permanent blindness” means irreversible and uncorrectable loss of vision, which is seriously disabling with no prospect of recovery. Serious disability is equivalent to visual acuity of less than 20/200 Snellen measured using both eyes.

This protocol did not stop the development of laser weapons because only laser weapons specifically designed to cause blindness are banned by the protocol. As a matter of fact, Article 3 opens the door to lasers that blind as long as that was not their aim. For instance, HELs are exempt from the ban because they are built to attack targets such as missiles or aircraft. The same thing applies to anti-sensor LELs. Finally, all anti-personnel lasers are allowed as long as they do not cause permanent damage to the naked eye.

8 Identification of opportunities

There are niches to fill in the domain of laser-based CM against laser beam rider and IR missiles. DRDC Valcartier is currently involved in such a development but the projects are supported by very small budgets (75K$ per FY). The opportunities are there but we will have to catch them. On the other hand, it is difficult to interest Canadian Industry because of the small size of the Canadian market. Joint ventures with the US or other partners are possible but require investments.

9 Relevant expertise within DRDC

As mentioned earlier, DRDC Valcartier is already involved in the development of LELs for dazzle of battlefield threats. At least one system has reached the state of advanced prototype while another is still in early development. It is planned through the technology demonstrator program to develop and demonstrate a combined non-lethal weapons CM systems capable of defeating most types of missile threats to aircraft. Moreover, since the development of laser-based weapons always involves a careful study of the laser safety aspects, an extensive laser safety know-how is essential. This know-how is already resident at DRDC Valcartier.

10 Recommendations

Laser weapons are a subject of keen interest from all military R&D laboratories and industries in the world. Laser weapons are here to stay because they have too many advantages not to be part of the Canadian Forces' inventories.

From a Canadian perspective, the domain of HELs requires too much investment for the capability of the country. Multi-hundred million-dollar budgets are mandatory to make significant achievements in the domain. On the other hand, LELs are far more accessible and DRDC is already involved in the development of some unique systems. Currently, we are the leader in the niches we have selected to explore and DRDC has been, several times, invited to demonstrate the technology through TTCP and bilateral agreements. However, we will have soon to go further in our development to maintain our leadership position. Also, industry will have to participate more in the developments.

DRDC Valcartier retains very good knowledge of general laser technology and, pending suitable support, could attack several niches in laser technology and contribute to larger foreign R&D programs.

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Annex C. Chemical Counter-Materiel Non-Lethal Weapons

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October 2003

1 Introduction

Since the beginning of the 90s, extensive search for new capabilities in military and law enforcement operations have brought to light many projects and technologies in the non-lethal weapons sphere. This study presents information on chemical counter-materiel non-lethal weapons (NLWs) gathered in the recent literature. In some cases, these weapons are worthy of science fiction, while others belong to a category of well-known police equipment. This study focuses on the existing and prospective technologies in chemical counter-materiel NLWs. The different weapons will not be presented as such but as technologies because they are at different stages of development.

Counter-materiel non-lethal technology is a general term defined as the means to disable or neutralize vehicles, vessels, aircraft, equipment and facilities [1]. This term includes technologies that would deny an area to vehicles, vessels and aircraft. In the literature, some authors use the term counter-capability more specifically to designate technologies designed to disable or neutralize facilities and systems and to deny the use of weapons of mass destruction [2, 3]. In this case, we will use counter-materiel as a general term which will only cover chemical technologies. Chemical counter-materiel non-lethal technologies are defined as means that include organic and/or inorganic compounds developed to react with other compounds or substances and/or produce the desired effects in counter-materiel applications [1].

The first decade of development of such technologies have made progress from concept formulation to practical implementation. There has been success in riot control agents, like Oleoresin Capsicum (OC), that could be applied to area denying. There was also success in aqueous foam technologies, which are now commercially available. However, many promising counter-materiel chemical technologies failed to progress because of legal restrictions. Also, many means are too aggressive and did not find applications due to environmental pollution. Besides, some of them do not have clear tactical applications [4]. The following sections will cover the situation of the different technologies.

2 Technology description

The chemical counter-materiel technologies can have two applications. The first one is area-denial, which includes technologies that aim at denying the area available to equipment or vehicles. They can be ground vehicles, ships, boats, vessels or planes. Such technologies might be able to degrade the responsiveness of vehicles or equipment, so that their operators would be reluctant to enter an area or find it extremely difficult to accomplish their missions. The second one includes technologies capable of disabling or neutralizing equipment, vehicles and facilities. For example, there are systems that alter the combustion properties of fuels, the viscosity of lubricants or the ability of vehicles to gain traction. Aside from their applications, chemical counter-materiel technologies can be divided into seven categories; namely, obscurants, reactants, anti-tractions, foams, malodorants, riot control agents and ancillary technologies.

2.1 Obscurants

Obscurants can be defined as a family of agents that obscure visual contact. They have been developed and first used in wartime operations to screen armed forces' view, signal friendly forces and identify enemy targets. They are suspended parts or adhesive agents that block or weaken the transmission of a specific part of the electromagnetic spectrum such as the visible, infrared or microwave. Foam, fog, mist, dust, smoke and ink are examples of obscurants. They were included in chemical counter-materiel non-lethal weapons because they could be used in applications such as denial of movement, area denial or delaying movement or attack. The obscurants would be effective in conditions where personnel or optical and/or vision systems are involved.

2.2 Reactants

The reactants are a family of technologies that are based on chemical compounds able to attack and damage structures, vehicles, roads or infrastructures. It is the reaction between the reactant and a specific target that cause the desired effect or modification. Many technologies are included in this category. For example, there are superacid mixtures, which are able to dissolve noble metals and organic compounds; there are also combustion modifiers, which can stop vehicles by altering the combustion process. The reactants are chemical counter-materiel technologies that have the capability to disable or neutralize certain vehicles, equipment and facilities. Chemical compounds can be used directly or in a binary or multicomponent chemical system for delivery. Despite their legality, including environment and health issues, and their lack of tactical applications, reactants could be useful, however, in some scenarios like vehicle disabling or structure attack in situations where a component destruction can challenge the opponent.

2.3 Anti-tractions

Anti-tractions are a family of chemical counter-materiel technologies whose aim is to stop/neutralize or deny area to vehicles or equipment by creating a slippery area on the ground. This technology cannot be applied to ships or vessels but it can to aircraft. Anti-tractions were mainly developed for counter-personnel applications, but some could be used in counter-materiel scenarios. Various chemicals like aqueous polymer solutions, liquid soaps, non-aqueous oils, polymer flakes or Teflon have been investigated. Despite their operational condition requirements, anti-tractions are promising technologies. They could be used in different scenarios, even when different types of terrain are present like grass, gravel, asphalt or concrete.

2.4 Foams

Three different kinds of foams are included in this category. There are rigid, aqueous and sticky foams. Rigid foam can be used to seal doors and windows, disable mechanical equipments, including weapons systems, contribute to barricades and deny access to materiel. Aqueous foam is a water-based foam with a very high expansion ratio. The main applications of aqueous foam are to blind or reduce the visual performance of vehicles or equipments or to be a matrix for riot control agents. It also has the capability to delay access or to be a complementary useful attenuator of explosive energy. When laced with riot control agents, malodorants or calmatives they would fall under the Chemical Weapons Convention (CWC). For its part, sticky foams are a promising technology already used in some police departments for counter-personnel applications. It was developed to deny area to personnel by creating a sticky area on the ground. Sticky foam could also have counter-materiel applications in access delay or area denial of small vehicles or equipments. However, few developments for counter-materiel applications have been successful. Current sticky foams are made of various chemicals like rubber or resin.

2.5 Malodorants and riot control agents

Malodorants and riot control agents are a family of chemicals or biological agents that include a series of psychoactive and physical active substances whose main effect is to incapacitate personnel. This category was included in the counter-materiel technologies because these agents would affect materiel when it is personnel dependent. The chemicals inside these technologies would first physically or psychologically affect personnel and then cause materiel to stop or be neutralized. It could also prevent materiel from entering a specific area, where these chemicals are present. They are legally accepted when defined as riot control agents used for law enforcement. However, they would violate the Chemical Weapons Convention when used as a warfare agent. They could possibly be used in peacekeeping missions or in operations other than war by offering new strategic possibilities; the situation is not clear about their legal use in these situations.

2.6 Ancillary technologies

Ancillary technologies are related to chemical counter-materiel NLWs. Two technologies were extracted from the literature: microencapsulation and smart metals. Microencapsulation enhances the delivery of technologies like sticky foams or superacids, while smart metals offer new strategic possibilities.

The following table describes in detail each technology, concept and system extracted from the literature related to chemical counter-materiel non-lethal technologies. For information purposes, unsuitable and speculative concepts will be presented. A brief description of the various technologies, concepts and systems and their assumed effects will be included. Even if the technologies are relatively well described in Table 1, this does not mean that they are completely developed, as will be discussed in Table 2. One must be careful about the credibility of and the allegations made about certain technologies in the literature, since there are few analyses and details on chemical counter-materiel technologies. For example, no superacid can dissolve a tank in a few minutes, as has been purported in some papers.

Table 1: Chemical counter-materiel non-lethal technologies, their descriptions, assumed effects and possible applications

Technology	Description	Assumed effects	Possible applications
Obscurants			
Rapid hardening agents	Polymer-based agents that rapidly expand and harden quickly.	Deny vision through affected device or port.	Used to obscure the vision ports/optics of an armoured fighting vehicle.
Smokes (white or coloured)	Obscuring smokes delivered by grenades or smoke pots, Relatively inexpensive, non-toxic, non-contaminating. Some smoke systems are combined with riot control agents (CS or OC).	Deny or reduce vision to confuse, disorient, and incapacitate individuals. Obscuring smokes with riot control agents are temporarily irritating to the nose and throat and make those affected lose visibility, sense of purpose and direction.	Deny access and establish perimeter (e.g., around a ship).
Advanced obscurants, including IR capabilities	Smokes that produce infrared obscurants.	Obscurants will degrade thermal imager.	Deny access and establish perimeter (e.g., around a ship).
Thermobaric technology	Explosive-like compounds that do not detonate but evolve their energy with significant thermal release over a relatively long time.	Causes extended flash, sound, temperature, and pressure conditions to disorient and/or temporarily incapacitate individuals or vehicles.	Potentially useful for area denial.
Dense fogs	Dense fogs produced with water and propylene glycol mix [5]. Particles are about .05 microns.	Deny or reduce vision and thermal sight.	Used to blind vehicles or equipments or reduce thermal sight performance.
Reactants			
Supercorrosives, superacids or supercaustics	Highly corrosive acidic compounds. Known as supercaustics, superacids, supercorrosive bases and C+.	Can dissolve most metals and alloys, organic compounds, ceramics and some polymers.	Could be used to attack structures, vehicles, tires, roads, rooftops and optical systems. Corrosive agents proposed to be useful against electrical components and other materiel.
Combustion alteration by fuel viscosity or fuel contaminants	This technology consists of chemical additives that either contaminate or change the viscosity characteristics of fuel to degrade standard engine performance.	Additives may be ingested as a vapour through air intakes, mixed with fuel during the intake cycle or applied directly to a fuel source causing almost instant engine failure.	Stop or neutralize vehicles, boats, ships or planes.
Combustion alteration, air/fuel, or combustion modifiers	Chemical agents ingested through air intakes, which inhibit the combustion of the air/fuel mixture.	Inhibit the combustion process by depriving it of oxygen.	Stop or neutralize vehicles, boats, ships or planes.
Lubricant contaminants	Agents used to contaminate lubricants.	Destroy lubricating ability. Can be introduced directly to store lubes or deliver them directly to vehicles in the field by munitions such as ferret rounds.	Stop or neutralize vehicles.

Technology	Description	Assumed effects	Possible applications
Depolymerizers	Chemical compounds that induce breakdown of chemical bonds in polymers.	Cause breakdown in rubber-based materials such as tires and other plastics.	Stop or neutralize vehicles, equipment and aircraft.
Embrittlers	Agents that operate by altering the molecular structure of basic metals or alloys.	Cause metal structures to become brittle and irreversibly lose their structural strength. Have potential human effects due to agents themselves or injury due to failure of affected vehicle or structures.	Stop or neutralize vehicles, equipment, boats, ships and aircraft.
Emulsifiers or emulsifying agents	Agents contained in a mixture of mutually insoluble liquids.	When dispersed over the ground, create a quicksand-like surface which can inhibit foot or vehicle travel. Also known as soil destabilizers.	Stop or neutralize vehicles, equipments, deny access.
Supersolvents	Solvents with a strong capacity to dissolve rubbers	Dissolve "O" rings present in vehicles.	Stop or neutralize vehicles, equipment by dissolving "O" rings.
Thermites, propellants	Thermites are a group of pyrotechnic mixtures in which a reactive metal reduces oxygen from a metallic oxide. This produces a lot of heat.	Can be used to fuse elements of metallic platform; can melt metal with the temperature produced.	Stop or neutralize vehicles, equipment.
Contaminating abrasives	Fine metallic materials.	Materials put into engines to degrade precision parts.	Stop or neutralize vehicles, equipment.
Microfibres	Super strength microfibres coming from genetic research on spiders.	Reversible immobilization of personnel and equipment by entanglement, temporarily disabling equipments.	Temporarily stop or neutralize vehicles, equipment (e.g., fouling propellers or fan blades) by entanglement.
Cloggers, vessel exhaust stack blockers	Systems used to block vessel exhaust on boats/ships.	Systems that explosively expand to completely seal the stack. Then, the engine shuts down without damage from a buildup of exhaust back pressure preventing fresh air intake.	Stop boats and ships.
Air intake blockers	Thin films or fabrics deployed over a battle tank and drawn tightly over the air intake by airflow.	Targets are internal combustion engines or turbines preventing fresh air intakes.	Stop or neutralize vehicles, equipment.
Antiadditives	Agents that counteract lubricant additives.	Disable antiwear and antioxidant additives in lubricants, causing an engine to stop.	Stop or neutralize vehicles, equipment, ships or boats.
Anti-tractions			
Slippery foams and agents	Substances that cause lack of traction.	When spread on a walkway, make crossing the area difficult for vehicles. Could have lethal effects when used directly on personnel.	Stop or neutralize vehicles, equipment. Area denial to vehicles, equipment. Disable facilities or structures' entries and exits. Cannot be applied to stop ships or vessels.

Technology	Description	Assumed effects	Possible applications
Foams			
Foams – rigid, barrier	Foams applied with a hand-held dispenser; harden and become rigid in about 15 minutes.	Rapid dispersion and hardening of foams useful for base security and barrier functions; removal and cleanup have proven difficult.	Make equipment, vehicles and some weapons inoperable. Disable facilities or structures' entries and exits. Mainly used as barriers. Used to breach obstacles or fill gaps. Applications vary depending on foam expansion ratio and volume needed [6].
Rigid polyurethane foams	Materials that offer the elasticity of rubber combined with the toughness and durability of metal. Urethane is available in a diverse range of hardness.	Rapid dispersion and hardening of foam useful for base security and barrier function.	Deny access to vehicles, equipment. Secure buildings. Applications vary depending on foam expansion ratio and volume needed [6]. Could be used as adhesives for attaching equipment. Specifically, they can seal doors, windows, manholes; disable mechanical equipment, including weapon systems, contribute to barricades, deny access to materiel, and provide visible/IR obscurance [7].
Aqueous foams – with or without riot control agents	High expansion water-based foam; applied with a hose from a tank truck or similar vehicle with pump and foam generator.	Large expansion ratio, for use as visual and acoustic isolation, and fire suppression; irritant could be added, though certain chemicals were found to be safe against humans. Impedes mobility and causes disorientation.	Used to blind vehicles or equipment or reduce their visual performance. Also used to hide mechanical barriers to impede their avoidance. May also be laced with riot control agents (pepper spray, CS, malodorant, calmative). Can be treated to mitigate biological warfare [8, 9].

Technology	Description	Assumed effects	Possible applications
Sticky foams – sticky thermoplastic foams	Polymer adhesives used to stop or neutralize vehicles or equipments.	Restrain/incapacitate vehicles or equipment.	Developed for access delay, area denial and target denial. The intention is to deny access to an area by creating a sticky area on the ground, which cannot be crossed by vehicles. The foams could also be used as adhesives for attaching equipment/devices to various hard and properly cleaned surfaces.
Underwater sticky foams	Sticky foams that work underwater.	Block swimmers, clog intakes.	Stop boats, swimmers.
Malodorants & riot control agents			
Malodorants	Chemicals that produce a very foul odour, which stimulates extreme revulsion to persons; foul smelling gases and sprays. Candidates include Scaptole and Mercaptans.	Their use in crowd control is currently limited by the unpredictable reaction of individuals. Temporary disorientation and potential repulsion of individuals by revolting olfactory saturation.	Potentially useful for area denial and to clear facilities.
Calmatives	Calmatives are chemicals or biological agents with sedative, sleep-inducing or similar psychoactive effects.	Incapacitate and disorient individuals depending on dosage.	Potentially useful for area denial and to clear facilities.
Riot control agents	Substances that produce temporary irritating or disabling physical effects which disappear within minutes of removal from exposure. There is no significant risk of permanent injury; medical treatment is rarely required.	Many assumed effects depending on riot control agents (irritate, disorient, respiratory effect, incapacitate).	Potentially useful for area denial and to clear facilities.
Pepper sprays (OC)	Sprays usually made with oleoresin capsicum, a pepper derivative (e.g., OC).	Incapacitate and disorient individuals.	Potentially useful for area denial and to clear facilities.
Lacrimators (CS)	Materials that strongly irritate the eyes, nose and mucous membranes and causes tearing (e.g., CS).	Incapacitate and disorient individuals.	Potentially useful for area denial and to clear facilities.
Riot control grenades	Grenades that spread substance (CS) which cause temporary irritating or disabling physical effects.	Riot control agents are expelled as vapours from the grenade.	Potentially useful for area denial and to clear facilities.

Technology	Description	Assumed effects	Possible applications
Ancillary technologies			
Microencapsulation	Systems used for the delivery of chemicals. Capsules with diameters as small as approximately 100 microns.	Allow safe delivery and controlled release; triggered by specific external stimuli such as pressure, heat, UV light and others.	Could be combined with other NLW technologies to enhance their properties. Possible combinations are combustion modifier and high viscosity polymer [10].
Smart metals	Special metals formed with chemical additives or blended in a particular form so that they would function only when used for legitimate purposes.	Give tell-tale signs of improper use or tampering.	Could be introduced to control certain activities, while allowing legitimate ones. Could give signs to inspectors if a plant is used for insidious purposes.

3 Technology situation

Along with the technology description of chemical counter-materiel technologies, the following paragraphs present their situations. Included with the situations, there is information on their present stage of development with comments and issues concerning their development. Moreover, information on their development location and investment will be added when available. Table 2 provides detailed information, but first an overview of the situation for each category will be presented.

3.1 Obscurants

The obscurants are mostly mature technologies. Various obscurants have been developed and used in military operations; many systems are commercially available. For specific non-lethal applications, new systems are being developed. Besides, ink for underwater applications and improvements on existing systems can expand the possibilities; for instance, including an IR capability to the current smoke systems [2]. Even if obscurants are well developped, they need to be evaluated and integrated in operational scenarios for counter-materiel applications. Finally, concerns about the obscurants are the environmental and health issues related to the chemicals used. Furthermore, concerns may arise when obscurants are mixed with riot control agents since they would be controlled by the CWC. Riot control agents are prohibited as warfare agents by the CWC, as it will be discussed in Chapter 5.

3.2 Reactants

At the beginning of reactant development, many were deluded by the potential of such technologies. However, with their development, many problems had to be faced. There are delivery problems because of the large quantities of chemicals needed and chemical reaction times which are often slow. Furthermore, chemicals are often aggressive and toxic for the environment and for personnel delivering the chemicals. Indeed, the legality of reactants is questioned, even for counter-materiel applications, since they would fall under the Chemical Weapons Convention because of their toxic effects to the delivery personnel. At the moment, reactants are not seen as promising technologies. However, with time and technological improvements, interesting technology might arise, such as combustion alteration technology which offers the possibility to stop a vehicle without damaging it.

3.3 Antitractions

Many chemicals have been investigated for anti-tractions. The development stage for counter-materiel applications was not determined because development was focused on counter-personnel applications. The effectiveness of this technology is often questioned because anti-tractions are surface dependent; they are more practical on smooth non-porous surfaces. Furthermore, weather conditions, such as rain, high temperatures and humidity, were found to reduce effectiveness [11]. Other problems, such as the large quantities needed and the removal of the material are considered to be major operational problems. There are also non-negligible human effects to be taken into account. For example, a fatal crash may happen. To counter the problems, new systems are under development, as the polymer-encapsulated lubricant, which offers better options like weather independence [12]. Finally, the technology is uncertain for counter-materiel applications, but may be promising in some scenarios when low-weight vehicles or equipment are involved.

3.4 Foams

The foams are at a relatively advanced stage of development and some are commercially available. For rigid foams, different chemicals have been investigated to improve long curing times, delivery and removal problems in order to make rigid foams more effective in an operational environment. Aqueous foams were first developed for other purposes than counter-materiel applications such as for blast attenuation purposes, but aqueous foams appeared to have counter-materiel applications as obscurants or matrices for riot control agents. New systems offer high expansion ratios, longer usable lifetimes and their instrumentation is simple. The issue with aqueous foams is the removal in an operational environment and the toxicity of some chemicals used. Even if this technology offers some potential, a lack of operational utility can be expected [1]. Sticky foams are well developed for counter-personnel applications, but not for counter-materiel applications. New developments were noticed, such as underwater sticky foams designed to stop boats by blocking the intakes [2]. The main issue with sticky foams is cleanup. Other issues, such as toxicity and potential for suffocation, can arise when persons are involved.

3.5 Malodorants and riot control agents

Malodorants and riot control agents are coveted and offer promising technologies for counter-materiel applications. Generally, research in this field is advanced and some highly effective compounds with safety margins have been identified, as riot control agent OC which is now used by the Canadian police community. Research is still needed, however, for calmatives and malodorants to counter issues related to their effects, susceptibilities, safety, delivery methods, and proper dose vs. exposure. Their uncertain legal issues when used in situations other than law enforcement have caused many projects to be compromised. At present, the US authorities, in accordance with treaty obligations, are launching new projects involving malodorants and calmatives [2]. This category is ethically criticized and legally uncertain, as will be discussed in Chapter 5.

3.6 Ancillary technologies

Ancillary technologies are very promising technologies in general and few are related to counter-materiel applications. Combined with existing chemical counter-materiel technologies, ancillary technologies can improve their effectiveness. For example, the use of microencapsulation tends to solve delivery problems, a drawback for many technologies. Ancillary technologies will probably define the future of chemical counter-materiel technologies.

Table 2: Chemical counter-materiel non-lethal technology situation, technology readiness level, development locations and investments

Technology	Situation and technology readiness level (TRL)	Development locations and investments
Obscurants		
Rapid hardening agents	TRL: Not determined	US; not investigated by Joint Non-Lethal Weapon Program (JNLWP).
Smokes (White or Coloured)	TRL: Available for procurement with sophisticated delivery methods. Some medical studies have been carried out on types of "smokes" used in the military and fire service training. They show that long-term toxicity effects are possible, depending on the exposure and chemical content of the smokes [13]. TRL France: Not determined [14]	US; commercial-off-the-shelf, existing payload developed prior to JNLWP-Army stockpile. Police Scientific Development Branch (PSDB) has found devices too indiscriminate and potentially dangerous. France has suggested smokes based on aerosols containing solid or liquid products. The formulation may be adhesive on glass windows, which could improve the efficiency of the product.
Advanced obscurants, including IR capabilities	TRL: Mature technology In use with various dispensers, IR capabilities relatively new.	US; program underway at Sandia.
Thermobaric technology	TRL: A feasibility study is underway to determine the usefulness of thermobaric weapons to accomplish non-lethal missions; counter-personal application has been identified for this technology [2, 8].	US, JNLWP Non-lethal Environmental Evaluation & Remediation (NEER) Center at Kansas State University will assess the materials proposed for environmental issues 15]
Dense Fogs	TRL: Initial development and experimentation of a dense fog has been performed [5]	US Army, Armament Research, Development and Engineering Center, Picatinny Arsenal, New Jersey.

Technology	Situation and technology readiness level (TRL)	Development locations and investments
Reactants		
Supercorrosives, superacids, supercaustics	TRL: System not determined, but chemicals well known.[14]. Difficult delivery of materials is a drawback, precise placement needed. Chemicals are toxic to personnel and environment; however, when delivered with pinpoint accuracy and in small amounts, they could be efficient. Reaction time is relatively slow.	US Chemicals have many industrial applications.
Combustion alteration, fuel viscosity or fuel contaminants	TRL US, Not determined Potential combustion modifiers and/or lubricant degradants in both gasoline and diesel engines have been identified by Edgewood [16]. Fuel thickeners demonstrated with thixotropic gels. Difficult delivery of chemicals on moving targets is a drawback, with little chance of extensive use. Generally, a large amount of material is needed. TRL France, Properties in static conditions are well known for some chemicals [14].	US; under study by Edgewood Chemical and Biological Command (ECBC). France has suggested: modification of octane number; decreasing it with paraffin or increasing it with methyl ether. Alkaline metals can also modify combustion dramatically.[14].
Combustion alteration, air/fuel, or combustion modifiers	TRL: Not determined Effective during tests; difficult delivery of chemicals on moving targets is a drawback. Two types have been tested; knock producers and engine runaway agents Nanoparticules dispensed to create engine combustion disturbance have been proposed. However, nanoparticles are very expensive for the moment.	US; former program at ECBC. France has suggested gaseous fluorocarbon (Halon) to stop engine ignition. The delivery system could be an aerosol containing fluorocarbon and viscous products such as neoprene or chloroprene to combine two effects. Plugging air intake and ignition modification [14] .
Lubricant Contaminants	TRL: Not determined Difficult delivery of materials is a drawback.	US; Sandia National Laboratories were involved in lubricant and grease additives to immobilize.[17]. France has suggested modification to the additives of the lubricants, leading to a deterioration of their properties. Ceramics precursors that transform themselves into abrasive particles with heat were also mentioned. Addition of detergent to form air bubbles in lubricants was also suggested [14]
Depolymerizers	TRL: not determined Could be useful in some scenarios. Delivery methods remain a problem because large amounts of chemicals are needed. Demonstrated small-scale rubber de-polymerizers were based on an oxidation mechanism. Current tires contain anti-oxidants not present in previous work. Injection of chemicals directly into tires rather than from outside could be a realistic solution to the delivery problem.	US, Los Alamos National Laboratory; tests performed in the past [2, 18].

Technology	Situation and technology readiness level (TRL)	Development locations and investments
Embrittlers	TRL: Not determined Embrittlers can be liquid metal embrittlers, which cause corrosive degradation of metals. Occurs in specific conditions; only certain metals are corroded; depends on many factors such as grain size and metallurgical state [19, 20]. Reaction time is slow and damage irreversible. Could produce a high degree of environmental damage if applied in large quantities. No major health effects, however.	US France has suggested hydrogen with a direct current source, sulphidated vapours and liquid metals (gallium that embrittles aluminum) [14]. Embrittlement of metals is a major concern and the subject of studies by industry.
Emulsifiers or emulsifying agents	TRL: Not determined Technology used in the past; emulsifiers were dispersed over the Ho Chi Minh trail to degrade the logistical lifeline of Viet Cong forces during the Vietnam War.	US; emulsifying agents are used in food processing, drilling fluids, cosmetics, pharmaceuticals, heavy-duty cleaners, textile manufacturing, pulp and paper processing, adhesives, sealants and agricultural products.
Supersolvents	TRL: Suggested technology	US
Thermites, propellants	TRL: Suggested technology, basic principles are known.	US; suggested by Sandia and Lawrence Livermore National Laboratories. Thermites are used in many applications, ranging from igniters in automobiles airbags to welding [21].
Contaminating abrasives	TRL: Not determined	US; Sandia National Laboratories [8] France has suggested that soluble ceramic precursors thermally labile would be a way to introduce abrasive materials in engines [14]
Microfibres	TRL: Not determined Technology assessment of genetic research on spider fibres. Understanding and reproducing the organic structure has proved elusive. Study terminated in December 1998. Technology remains on the watch list by US authorities.	US; University of New Hampshire, U.S. Army Natick Research, Development and Engineering Center and Nexia Inc.
Cloggers, vessel exhaust stack blockers	TRL: Not determined; systems have been tested. Operationally difficult to position over a ship by helicopter. Exhaust stack blocker tested; difficult delivery is a drawback; helicopter delivery terminated.	US concept exploration program by JNLWD System tested at Naval Surface Warfare Center, Carderock Division.
Air intake blockers	TRL: Not determined	US; Edgewood
Antiadditives	TRL: Not determined Effective in 1 to 2% concentrations. Disable antiwear and antioxidant additives in the lubricant.	US proposition, based on previous work; program currently inactive [2]

Technology	**Situation and technology readiness level (TRL)**	**Development locations and investments**
Antitraction		
Slippery foams and agents	TRL: Under development, demonstration effective on personnel. Also known as Mobility Denial System [22]. US Army has tested many chemicals like water-activated dry polymer powders, hydrocarbon-based lubricants, Teflon, detergents and polyethylene confetti [11, 23]. Require large quantities of materials to be delivered (logistic problems). Hazard to moving vehicles, which may become involved in fatal crash. Needs are effective at low and high loads (small equipment vs. airplanes), low slump, non-displaceable and non-toxic [23]. Weather dependency, removing and dissemination methods are issues. Water-activated polymers are promising to counter environmental and health issues.[23]. New systems are under development like polymer-encapsulated lubricants, which offer better options like weather independency (Lehigh University) [12].	US; currently in development under JNLWD sponsorship. Edgewood and Southwest Research Institute [22, 23]. Academic research underway, Lehigh and New Hampshire Universities. Investment made by National Defence Industrial Association (NDIA) for FY00 [24]. Environmental evaluation by NEER at Kansas State University [15, 25]. France has suggested a solid lubricant (graphite, molybdene bisulfide, polytetra fluoroethylene, polyethylene) mix with an adhesive resin [14].
Foams		
Foams – rigid, barriers	TRL: Active research and development has been initiated. Applied with a hand-held dispenser, it hardens and becomes rigid in about 15 minutes. Long cure time limits their operational utility. Removing is an issue.	US; academic research underway at University of New Hampshire [2]. Southwest Research Institute has investigated the use of rigid foams for area denial [11]. Some commercial rigid foam systems were developed for other purposes [11]
Rigid foams (polyurethane)	TRL: Foam materials and dispensers made and tested Polyurethane foams have been used for over 50 years by industry. This family of polymer is very versatile, both in terms of application and chemistry. Composition can be adjusted to obtain materials of various rigidities and foam/gas contents. Should not be used against humans Faster cure time are needed. Removing is an issue.	Foam materials and dispensers made and tested at Sandia. New Hampshire University has made improvement on the foams. Industrial products are currently available (ex. thermal insulation for buildings).

Technology	Situation and technology readiness level (TRL)	Development locations and investments
Aqueous foams – with or without riot control agents	TRL US; system prototype demonstration in an operational environment. No current military requirement [1] TRL UK; system prototype demonstration in an operational environment; a thicker derivative of aircraft firefighting foam. TRL Netherlands: not determined Selection of ingredients can minimize human interaction problems [26]. Removing is an issue in an operational environment.	US; foam materials and dispensers made and tested at Sandia National Laboratory [2, 8]. Sandia National Laboratories have developed foams for applications related to nuclear industry and in prison scenarios. [11] US Army. Edwood Research and Development Engineering Center; research on area denial aqueous foams [11]. The Netherlands [1] have worked on aqueous foams with riot control agents (CS). France has suggested to use a bipolymer such as agarose, carageenan or Gelan because of their non-toxicities [14].
Sticky foams – sticky thermoplastic foams or sticker and superadhesives	TRL: system prototype demonstration in an operational environment for counter-personnel applications. Common ingredients include rubbers, resins, oils, fire retardants and stabilizing chemicals. Some toxic chemicals, like chlorofluorocarbons (CFC's) or hydrochlorofluorcarbons (HCFC's), can be present [27]. Silicone-based sticky foams offer broad temperature range and low toxicity [27]. Antidote to become unstuck from the sticky foams is needed. Contact with eyes, mouth or nose are issues that led to a shift for more counter-materiel applications. Removing is an issue.	US; foam materials and dispensers made and tested at Sandia National Laboratories [2, 8]. Police Scientific Development Branch has found devices that do not require further research. Canada's energetic thermoplastic elastomers from DRDC Valcartier could be adapted to sticky applications.
Underwater sticky foams	Idea was discussed, work is unknown.	US

Technology	Situation and technology readiness level (TRL)	Development locations and investments
Malodorants and riot control agents		
Malodorants	TRL: prototype demonstration in a relevant environment [1] ; mechanism of action is well understood [2]. Systems under consideration for counter-personnel and counter-materiel applications. Determination of most offensive scents, consistent production of desired human response and dosage were studied. Human effects are unknown, smell lingering effects are a concern [28]. Might be delivered by hand grenades, mortars, planes or missiles. Repulsiveness depends largely on cultural background of test subject. Mixture of malodorants and irritants could circumvent this limitation. Efforts are made to link particular smells with emotional responses such as pain and fear. Prohibited as warfare agents by the CWC. Could be confused with chemical weapons of a more lethal nature [29].	US; sponsored by JNLWP Many odors tested and evaluated for environmental issues. NEER at Kansas State University [15, 28, 30]. The Netherlands Perfumes and flavour industries may be capable of developing suitable odours.
Calmatives	TRL: Basic principle observed and reported, further research needed on delivery [1]. Further research required involving effects, susceptibilities, safety and delivery methods. The use of dimethyl sulfoxide (DMSO) with calmatives promotes rapid absorption through the skin. The problem of delivery safety could be solved by applying calmative and antidote simultaneously or subsequently. Considerable human effect work needed to develop composition and dosage that achieve consistent universal effects. Prohibited as warfare agents by the CWC.	US; under study by Edgewood Chemical and Biological Command after suspension of R&D for 10 years. Work was suspended because of perceived liability issues surrounding the injection of drugs without consent. In 2002, Russian forces gassed a building with a calmative agent designed to put everyone inside to sleep. More than 100 hostages died from the dose.
Riot control agents	TRL of OC (Oleoresin Capsicum) and CS (Orthochlorobenzalmalononitrile): systems used under operational mission conditions, mechanism of action is well understood [2]. TRL of CS1, CS2, CSX, CA, CN, chemical mace, CR and invisible tear gas: not determined. Many propositions for a combination of riot control agents with other non-lethal technologies to enhance properties [31]. Prohibited as warfare agents by the CWC.	US; ECBC, technology investment program study underway for military use and new potential systems. Kansas State University has been working on environmental degradation of riot control agents. All compounds are biodegraded when environmental conditions are appropriate [32]. Canada has worked with OC and CS [1]. The Netherlands have experience in this field [1]

Technology	Situation and technology readiness level (TRL)	Development locations and investments
Pepper sprays (OC)	TRL: systems used under operational mission conditions. Used by police and coastguard in counter-personnel applications. Hazard depends on dosage; [33] cleanup is an issue. Prohibited as warfare agents by the CWC.	Available for procurement Developed by ZARC International Used in Rwanda, Haiti and Somalia by US troops. Canadian Forces have stockpiles of pepper sprays.
Lacrimators (CS)	TRL: systems used under operational mission conditions. Used by police in counter-personnel applications. Hazard depends on dosage. Prohibited as warfare agents by the CWC.	Available for procurement UK; most widely used chemical incapacitants within the UK police.
Riot control grenades	TRL: systems used under operational mission conditions. Hazard depends on dosage and type of casing. Prohibited as warfare agents by the CWC.	US; current payload available from army stockpiles. UK
Ancillary technologies		
Microencapsulation	TRL: active research and development is initiated. Potential use in chemicals' delivery (e.g. sticky foams). Could be designed for pressure, temperature or chemical release when needed.	US; academic research underway at New Hampshire University; under study by JNLWD.
Smart metals	TRL: Not determined	US; not investigated by JNLW; potential for NLW applications.

4 International

Research and development on chemical counter-materiel non-lethal technologies is limited and the level of international work involvement is stable. Many technologies have been put forward; now, the focus is mostly on problem-solving issues related to promising technologies and on their integration in an operational environment. In the last decade, much of the exploratory work was performed under the US Joint Non Lethal Weapons Directorate (JNLWD). This organization is in charge of centralizing coordination and integration of NLW technologies in the US Department of Defense. Various laboratories were involved. One important facility related to chemical NLWs is the Edgewood Chemical and Biological Command. The ECBC was involved in combustion modifiers and also in the development of a solid expertise in malodorants and riot control agents. However, these efforts have been reduced in recent years with the adoption of the Chemical Weapons Convention by the US. Other US laboratories, such as Sandia National Laboratories, were involved in research on obscurants, lubricant contaminants, contaminating abrasives and various foams. Also, the Los Alamos National Laboratory have studied the depolymerizers' aspects of NLWs. [17]. The National Institute of Justice has approached NLWs by supporting the law enforcement R&D effort [2]. Indeed, it has worked on the assessment of the Oleoresin Capsicum (OC) effects [34]. The Armament Research Development and Engineering Center (ARDEC) and Army

Research Laboratory (ARL) also had a few R&D programs involving chemical counter-materials, such as foams, antitractions, combustion modifiers and engine cloggers [35]. Supported by JNLWD, some US universities were involved in the development and evaluation of chemical counter-materiel non-lethal technologies. For instance, at the University of New Hampshire, a non-lethal technology innovation centre has evaluated technologies such as rigid foams, antitractions and microencapsulation. Lehigh University has also worked on the improvement of antitractions. Besides, two other universities were mandated to evaluate some chemical counter-materiel technologies. First, Pennsylvania State University owns the Institute for Non-lethal Defense Technologies. One of its tasks was to assess the human effects of certain technologies; for example, calmatives were assessed. Second, Kansas State University has its Non-lethal Environmental Evaluation & Remediation center (NEER). It has studied environmental issues associated with certain chemical counter-materiel non-lethal technologies and evaluated technologies such as antitractions, thermobaric technology, malodorants and riot control agents.

Related to the investment made in chemical counter-materiel technologies, few amounts were found explicitly in the literature. The main investment came from JNLWD in the US for exploratory work. The total investment from JNLWD for all NLW R&D programs mostly came from the US Navy and the US Army, which represented 25 million $ 2001 and is projected to be 35 million $ in the next years [2]. Besides JNLWD, practically no work has been carried out on non-lethal R&D in the US. That might change in the years to come due to the increasing interest in non-lethal weapons and to the fact that many of the draft requirements indicate a move to integrate non-lethal capabilities within operational environments [5]. This could lead to the development of collaborations within countries.

Outside the US, there was related involvement in chemical counter-materiel technologies. First, NATO adopted a policy on non-lethal weapons. In the UK, the University of Bradford reviewed NLW systems that are now in use and others that are under development for civil law enforcement and military operations. Possible threats from NLWs to current and future chemical, biological, conventional and inhumane weapons conventions [19, 36, 37] were examined. Defence Science and Technology Laboratories (DSTL) and the Police Scientific Development Branch in the UK were also involved. In the Netherlands, the Joint TNO Defense Research, a ministerial defense research program, has assessed the utility of NLWs for the country. Moreover, in chemical counter-materiel technologies, work has been carried out on aqueous foams mixed with riot control agents, on malodorants and riot control agents. In other countries, no such programs exist. France could be added to the list, however, since a group of experts has made a critical survey of chemical counter-materiel technologies such as obscurants, combustion modifications, lubricant contaminants, sticky foams, antitractions and rigid foams [14]. Finally, there is working group on non-lethal weapons in European countries, including Austria, Switzerland, Germany, Italy, the Netherlands, Sweden and the UK. The group focuses on European activities in the field of NLWs, determines promising research fields, initiates co-operation across countries involved and avoids duplicitous work effort.

A series of international conferences have brought out discussions on chemical counter-materiel technologies within presentations. The Non-Lethal Defense conferences within the US National Defense Industrial Association (NDIA) have discussed thoroughly about chemical counter-materiel NLWs. During the NTAR conferences held at the University of

New Hampshire, interesting papers were also presented, on new delivery systems such as microencapsulation, for instance. Outside the US, a conference held at the University of Bradford in the UK discussed the future of Non-Lethal Weapons, including technologies, operations, ethics and law. Finally, European symposia on Non-Lethal Weapons were held in 2001 and 2003.

Collaborations took place between countries within the European working group. Furthermore, the UK and the US worked closely on the development of NLWs within an exchange program [35]. Industry's involvement was limited to the providers of riot control agents [38], obscurants and foams, which were not sold specifically as counter-materiel NLWs. As a matter of fact, no company was involved in chemical counter-materiel NLWs, except Primex, a subdivision of General Dynamics and a major weapon builder, which has worked on delivery systems for calmatives and malodorants [29]. However, it is well known that JNLWD called for bids from commercial companies in the area of counter-materiel non-lethal technologies.

5 National

In Canada, work on chemical counter-materiel non-lethal technologies is limited to activities related to riot control agents. The Canadian Police Research Centre and some police units have conducted research on the feasibility of using pepper sprays within their departments for counter-personnel applications. Aside from that, there are no other Canadian R&D programs.

However, there is some related Canadian expertise. For instance, the Canadian Police Research Centre has worked on foam formulations for blast guard systems [39]. DRDC Suffield also conducted research on foams., more specifically on the explosion attenuation properties of aqueous foams [40, 41]. Moreover, solid polyurethane foams used as low-density distribution explosives in water have been evaluated [42]. Furthermore, DRDC Valcartier worked on developing and improving obscurants [43, 44], through its facility dedicated to take quantitative and qualitative measurements of obscurants from the UV to the far-infrared bands [45]. The National Research Council of Canada has also some related expertise through its technology group on polymer foam research [46]. Canadian universities and industries have only little related expertise.

6 Canadian Forces' perspectives

The Canadian Forces must be ready to face multiple situations like peacekeeping, law enforcement, drug interdiction, disaster response and force protection. They will be more and more confronted with increased media attention, environmental concerns and low national tolerance towards military operations. Non-lethal capabilities could expand the options and tools available to the commanders to optmize their operations [47]. Non-lethal technologies could provide the political decision-makers and military commanders with the means to dominate the portion of the spectrum of force that lies between diplomacy and lethality [19]. NLWs represent a small field in the armament industry, but they will play an increasing role in future operations within the context of technological advances, police and military operational requirements, political demands and humanitarian influences. The proliferation of NLWs in military operations is inevitable [19].

In the case of chemical counter-materiel non-lethal technologies, they offer mostly new stategic options to the commanders, while minimizing damage to adversary materiel. They can be used for area denial and disabling vehicles, vessels and facilities. The different options provided, as seen in Tables 1 and 2, are interesting from a military point of view. However, they have several constraints, such as effective reaction time, imprecise delivery, proper dosage, weather dependency and possible environmental and human secondary effects, which may limit their use. Applications over a broad area sometimes require a significant amount of agents, which may complicate effective targeting. As a result, chemical counter-materiel technologies are best used in given situations. In most cases, the effects will be short lived until the substance is removed or countered. They are also best used in situations where the need is for a small delay in the enemy's maneuvering, such as blocking enemy's critical supply, for instance.

In the last few years, chemical counter-materiel NLWs has made progress and some are more adapted to the needs of military operations. Some are advanced, especially those needed for area denial applications, like obscurants, foams and riot control agents. Even pepper sprays (OC) are stockpiled in the Canadian Forces. But most are still at a preliminary stage of development, especially those used to disable vehicles, vessels or infrastructures like reactants. Prior to the development of chemical non-lethal technologies, the Canadian Forces must be careful about certain technologies put forward. It is hard to discriminate between the effects of lethal ammunition and non-lethal capabilities such as embrittlers or superacids. The destruction of a bridge by non-lethal chemicals or kinetic ammunition has the same results. Hence, non-lethal advantage or added-value, if any, must be weighed against the commander's confidence in the weapon [3].

The Canadian Forces will take into account the fact that some technologies could be used against them in future conflicts as weapons or countermeasures. For instance, antioxidants could be added to tires to counter depolymerizers' technologies based on oxidation. Therefore, this factor should be evaluated before developing the technologies. Many other factors must be taken into consideration prior to the development of non-lethal weapons. Other factors like weapon effectiveness, flexibility, deployability, tactical achievement and sustainability are likely to necessitate resupply and maintenance requirements; cost-effectiveness, needs and training necessary should also be considered. Taking into account these factors might raise new projects in order to adapt or transform the technology into an efficient and usable non-lethal weapon. Finally, facing the reality of NLWs and exploiting them will be a demanding task. The Canadian Forces must state a strategic plan based on the current strong assets and which enables DRDC to take actions imposed by future issues. The Canadian Forces must encourage the experimentation of technologies and new concepts because of the possibilities offered.

7 Ethical considerations

Inevitably, the use of NLWs will raise new ethical and moral issues concerning military operations. It is believed that non-lethal weapons might be ethically correct means, during wartime, since human and materiel costs would be lower. However, with the conflicts taking place nowadays, like peacekeeping, humanitarian assistance and law enforcement, the use of non-lethal weapons does not go without creating tensions associated with force. There are risks. The first risk, which could be called the slippery slope, involves an element of escalation in using NLWs. It may inadvertently lead to unintended and unwanted involvement [9]. A second risk is that NLWs could fall into the hands of persons with bad intentions and be used against our own forces. Another risk is that high technology systems might be vulnerable, especially when conflicts depend on them. Also, the risk emerges concerning unrealistic expectations and comparative cost-effectiveness. The possession of NLWs also raises the matter of legal or moral obligations to always use the lowest possible level of force [9]. Besides, several observers criticize the feeling of false safety associated with the term non-lethal. Yet, the probability of causing death still exists. In the field of arms control, non-lethal weapons could also invade the black market in armaments and escape from the usual controls of production and export [48].

Canada should consider many ethical aspects included in various laws, treaties and conventions by which it is bound. There are bans and humanitarian laws to which chemical counter-materiel NLWs are subjected [49]. Few treaties concern specifically NLWs, since their main target is to ban lethal weapons. According to the 1993 Chemical Weapons Convention (CWC), which covers chemical counter-materiel NLWs, a country shall never, under any circumstances, develop, produce, otherwise acquire, stockpile or retain chemical weapons of any kind, or transfer or use them. The definition of chemical weapons extends to toxic chemicals and their predecessors that, through their chemical action on life processes, can cause death, temporary incapacitation or permanent harm to humans or animals [49]. In view of this, the legal standing of some chemical counter-materiel non-lethal technologies, like superacids, may be questioned. In addition to corroding roads and tires, they may also have expected side-effetcs on human beings by causing harm to skin and flesh. If the chemicals in a weapon do not rely on their toxic properties to be effective, as is the case with counter-materiel applications, it may be "possible" to claim that the weapon is exempt, but the status has not been clearly established yet.

However, when toxic properties come into play, some exceptions are stated in the CWC. Prohibited chemical agents, like pepper sprays, may be developed and used for law enforcement purposes, for instance. The CWC does not ban chemicals themselves, but the purposes for which those chemicals are intended [50]. Again, when toxic properties come into play, it should be demonstrated that the chemical counter-materiel technology is not a warfare agent. but that its purpose is for law enforcement. Another convention closely related to chemical counter-materiel NLWs, the Environmental Modification techniques (ENMOD), imposes non-engagements in military or any other hostile uses of environmental modification techniques having widespread, long-lasting or severe effects as the means of destruction, damage or injury to any other state party [49]. Besides the treaties and conventions, some humanitarian laws apply to chemical counter-materiel NLWs. Included in those laws is the principle of discrimination according to which attacks shall be limited to military objectives, while methods that strike military objectives and civilians without distinction are therefore banned, as stated in the Geneva protocol [49]. This could cause difficulties with chemical counter-materiel non-lethal technologies since they often have delivery problems. Finally, also included in humanitarian laws is the principle of proportionality, according to which, when choice is possible, attacks shall be expected to cause the least danger to civilian lives and goods. The decision to prefer one result instead of the other could raise an ethical issue, especially if the preference goes to the lethal effect when a possibility of non-lethal effects was available. In conclusion, counter-materiel NLWs are subjected to the Chemical Weapons Convention, the Environmental Modification techniques and humanitarian laws and rights that apply directly to their development. With the current status of laws and conventions, the development of such weapons appears to be challenging legally and ethically.

Countries such as the US have further interpreted the CWC, so that certain technologies could be used in situations like peacekeeping. For instance, the Judge Advocate General and the Departement of the Navy under the Joint NLW program have completed a legal review and approved the development of NLWs technolgies in the light of laws and conventions [9]. They approved some chemical counter-materiel NLW candidates for acceptance in the US military inventory, such as superacids agents, embrittlers agents, depolymerizers, combustion modifiers, sticky foams and antitractions. Prior to following the US, Canada should proceed with its own survey, because other treaties might not be respected. For instance, sticky foams contain dichlorodifluoromethane or freon, ingredients that could raise an environmental law issue under the United Nations Ozone Treaty [33].

For antitractions, the Non-lethal Environment Evaluation and Remediation (NEER) Center, funded by the JNLWD, has considered environmental and remediation problems related to antitraction agents. It has taken into account the fate of products in the formulation, the health effects associated with chemicals that may be present and the impact of their repeated application, as well as the cleanup of the training area. It concluded that it is important to provide clear and timely environmental guidance as well as early proactive environmental evaluation included in the development of a product [51]. Canada should follow its example by developing new NLWs. In the case of malodorants and riot control agents, their use would violate the CWC because of their temporary incapacitating effects. Furthermore, they could easily be confused with chemical weapons of a more lethal nature.

Here is an example of the difficulty, from a legal point of view, of inserting chemical NLWs in combat. It happened during the Iraq War in the spring of 2003. US Pentagon officials attempted to craft simple rules of engagement for combat troops, making it possible for them to use riot control agents to incapacitate civilians in a given situation, but without success. During the war, the US troops were allowed to shoot and kill anyone, but they were not allowed to use non-lethal riot control agents [52]. This does not apply directly to counter-materiel NLWs since they are directed to materiel. However, if there is a risk that personnel could be affected, then the insertion of chemical weapons in combat will be difficult. It is important to consider the legality of use as well as the legality of the weapon itself, and the time is near, as antitractions that could cause a fatal crash to a car driver, if used improperly. However, this uncertainty should not imply that non-lethal weapons should be banned. As a matter of fact, their use should be encouraged. They are just at a low development stage and adaptation to an operational environment is needed.

8 Identification of opportunities

Research and development on chemical counter-materiel technologies should focus on improving capabilities. Capabilities will define future technologies as credible weapons [3]. Capabilities also include the possibility to use the technology while taking into account the ethical considerations discussed in the previous chapter. Here are some potential Canadian contributions:

- determining the utility of chemical counter-materiel technologies for the Canadian Forces;
- collaborating with US laboratories and other NATO countries involved in non-lethal weapons;
- adapting technologies to be usable in operational environments;
- identifying measures of effectiveness because of a poor understanding of the effects and effectiveness due to too fast a development;
- conducting trials with current and promising technologies;
- adapting and/or developing technologies in accordance with treaties and conventions;
- reducing environmental and health vulnerabilities;
- developing conflict-resolution strategies involving chemical non-lethal weapons;
- introducing new ideas.

Specifically, for each category of chemical counter-materiel technology, obscurants are already well developed, but they would need more advancement to be integrated into a military operational environment for counter-materiel applications. In the case of reactants, there are promising technologies, but most of them lack proper delivery systems for low risk, precise and accurate action. Improving the correct delivery systems for targets could make this technology acceptable and efficient in some scenarios. For instance, the development of an efficient delivery method for the combustion modifiers would make it a very strategic, non-violent, vehicle stopper system for the military. Before devoting the whole effort on reactants, clear tactical achievements must be determined, because low-tech means could often produce the same result. For instance, using nails instead of depolymerizers could stop a vehicle. The development of antitraction and foam technologies has been mostly focused on counter-personnel applications. Nevertheless, rigid foams appear to produce clear tactical achievement and should be considered. In the case of malodorants and riot control agents, their potential for counter-materiel applications should also be considered and evaluated more precisely. Their development should be directed towards very low-risk and humane temporarily incapacitating agents [53] to be used in given circumstances, like law enforcement. They could offer strategic possibilities for clearing facilities and area denial of materiel. However, there is a need to know about their real strategic impact and potential applications, if integrated into the Canadian Forces' inventory. As ancillary technologies, they are promising and there is a need for new ideas; microencapsulation, for instance, has created more effective technologies. Finally, the combination of different technologies must be evaluated. Mixing obscurants with riot control agents enhances the possibilities of both. Also, there are many development opportunities to obtain weapons that are reusable, effective and adapted to the field in terms of logistics, necessary training and maintenance support.

9 Linked DRDC expertise

DRDC does not possess specific expertise in chemical counter-materiel non-lethal technologies; however, it has related expertise. For instance, DRDC Suffield has a considerable source of knowledge on chemical and biological agents, their toxicology and infectivity, as well as on the behaviour of liquids, gases and aerosols released in the atmosphere. This expertise would certainly apply to the development or evaluation of malodorants and riot control agents or obscurants. The Chemical and Biological Section at DRDC Suffield has funded thrusts in hazard assessment, physical protection, medical countermeasures and verification of technology that could be related to chemical counter-materiel non-lethal technology development. Finally, DRDC Suffield has overall responsibility within DRDC to comply with the Chemical Weapons Convention.

DRDC Valcartier does possess related expertise in chemicals' development and analysis, especially in energetic materials. DRDC Valcartier also has expertise in weapons effects , as well as in vulnerability and lethality model effects. Its expertise in precision weapons could be useful, particularly in modeling and simulation. Besides, DRDC Valcartier's Munition Experimental Test Centre (METC) could be used for trials involving military vehicles or infrastructures. It is an essential tool for the development of chemical counter-materiel technologies. DRDC Valcartier has also acquired significant expertise in environmental issues concerning explosive materials. The assessment of the impact of chemical counter-materiel technologies on the environment is related. DRDC Atlantic, in Halifax, would certainly be interested in providing its expertise for naval R&D. It could be involved in the development of technologies related to vessels or ships.

10 Recommendations

Today's chemical counter-materiel NLWs are fascinating because of their opportunities, but developments are not being pursued at the moment due to many problems related to the technologies. For instance, treaties and conventions do not support their operational use. Besides, their effects and effectiveness are often not well defined and their potential secondary effects on humans and the environment are undesirable issues. The objectives can sometimes be achieved by other more favourable non-lethal means. However, some chemical counter-materiel technologies having interesting applications owing to their potential, usefulness and relation with Canadian expertise, are the following:

- *Combustion alteration* could offer the possibility to stop a vehicle without damage. Only a few non-lethal technologies provide this opportunity;
- *Rigid foams*, a well-developed technology, could offer real strategic possibilities, making equipment or vehicles inoperative;
- *Thermite propellants* could be an effective technology in some scenarios; DRDC Suffield and DRDC Valcartier possess knowledge in this area;
- Identification of opportunities for potential applications of *obscurants* as counter-materiel NLWs; *dense fog* for instance, seems to have potential;
- Investigate the needs and then be creative and innovative in developing new ideas; for instance, the combination of certain technologies has created new interesting opportunities.

The remaining technologies have been rejected because of their numerous issues and lack of tactical achievement. Finally, the Canadian Forces should focus on the development of a niche in chemical non-lethal weapons that are environmentally acceptable and used only for defensive and protection purposes. The needs of the Canadian Forces should be evaluated first; thereafter, it could be suggested that the Canadian Forces be involved in certain technologies or concepts in collaboration with the United States or NATO countries, since the development of such technologies can prove to be very expensive. Involvement in projects could lead to the creation of an expertise, so that DRDC would provide support and advice to the military customer. Finally, Canadian universities should certainly contribute to research and development on chemical counter-materiel NLWs. Universities' involvement would provide the transparency necessary for better public acceptance. DRDC could establish a working group with Canadian universities to actively oversee non-lethal weapon development and its blending into the Canadian Forces. Finally, the Biological and Chemical Defence Review Committee (BCDRC) could ensure that all activities within those programs are defensive in nature and conducted in a professional manner, with no threat to public safety or the environment.

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Annex D. Radio Frequency and Directed Energy Weapons

By

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December 2003

1 Description of the Technology

RF (radio frequency) weapons consist of non-nuclear electromagnetic pulse (NNEMP) and high-power microwave (HPM) weapons, whose energy is characterized by the long wavelength (low frequency) portion (radio waves and microwaves) of the electromagnetic spectrum.

A directed energy weapon (DEW) constitutes a system using directed energy primarily as a direct means to damage or destroy enemy equipment, facilities, and personnel.

1.1 High Power Microwave Weapons

High Power Microwave Weapons (HPMWs) are directed energy weapons, which are designed to attack a target by irradiating it with electromagnetic waves of high intensity over a certain distance. As indicated by their name, HPMWs use the microwave section of the electromagnetic spectrum, which we define to cover the frequency span from 300 MHz to 300 GHz, corresponding to wavelengths from 1 m to 1 mm. The label "high power" means that the microwave source in question is able to generate a peak power of more than 100 MW or an average power of more than 50 kW (where average power means the power averaged over one second).

The intended effect of an HPMW is to cause a function kill of the target attacked by disturbing, upsetting or damaging the target's electronics by HPM irradiation. This corresponds to the idea that HPMWs are primarily useful against "intelligent systems" and do not waste energy on mechanical destruction.

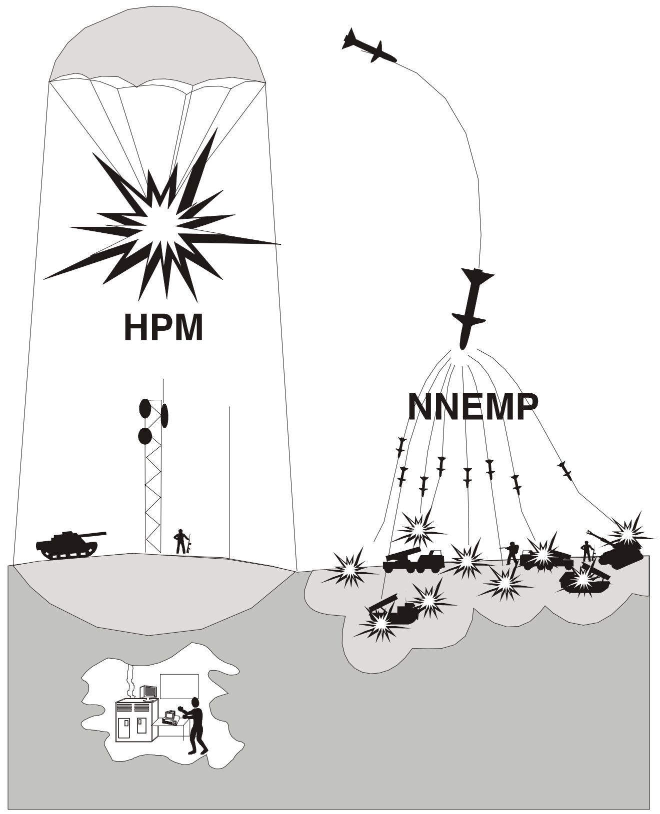

Figure 1 Conceptual Use of RF Weapons on the Battlefield

1.2 Advantages of HPMW

HPMWs form a new weapon category with a distinctive combination of advantages, such as:

- HPM energy propagates with the speed of light, many orders of magnitude faster than the fastest shell. This fact makes HPMWs operationally useful since it provides unprecedented short reaction times between, for example, the moment of target acquisition of an attacking sea skimmer by the attacked ship and the first impact from the ship's self-defence HPMW on the approaching missile.
- In most cases of mission-relevant upsets or damages, HPMWs need less than a millisecond to achieve the effect in the target irradiated. Adding the capability of electronic beam steering by means of phased array antennas, one HPMW could defend a ship against a concerted attack of many missiles, at least against those approaching from a fixed sector.
- HPMWs are ideally suited for low-intensity conflicts, information warfare and non-lethal applications since they attack the electronics of adversary systems rather than their munitions or personnel, and they go for a function kill of the target rather than for damaging its structure or harming its crew
- the growing use of COTS electronics is suitable for boosting the HPM threat.

1.3 The structure of HPM weapons

For all their diversity, HPMWs contain the following components for generating HPM,

- a prime energy supply which may be a battery, a diesel-driven electric generator or, for fixed ground stations, a connection to the power grid
- a pulsed power generator which accumulates the steady low-power output of the main energy supply for a longer period, stores the accumulated energy and releases it on command within a much shorter period (typically 1µs) as a high-power current pulse
- a power conditioning section which compresses and shapes the current pulse of the previous step further, by means of pulse forming transmission lines, capacitors, switches etc, and adjusts the pulse to the needs of the HPM source with regard to voltage, current, rise time and shape
- the HPM source proper which transforms as much as possible of the input current's energy into HPM field energy to be delivered to the target
- and finally the antenna for radiating the HPM field and concentrate it to the target as effectively as possible.

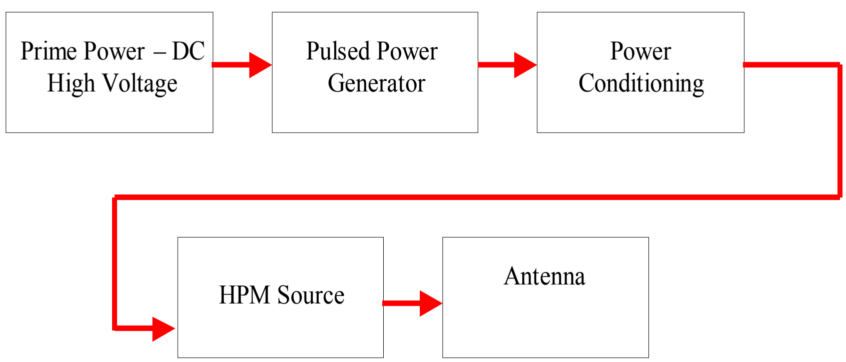

Fig 2 Generic HPM Source Block Daigram

2 How HPMWs affect their targets

On its way from the HPMW's antenna to the electronic circuits to be attacked, the HPM energy pulse passes through several steps, addressed briefly in the following paragraphs.

2.1 Beam propagation

While propagating through the atmosphere an HPM beam is attenuated by absorption and scattering but this attenuation depends strongly on frequency and weather. Restricting the discussion to tactical scenarios (i.e. ranges below 10 km, heights of weapon and target below 15 km) we find:

- For frequencies below around 7 GHz, microwave attenuation is negligible even in bad weather. Hence HPMWs designed for back-door attacks (see Section 2.2) are true all-weather weapons.
- For frequencies between 7 and 18 GHz, attenuation is still negligible in fair weather but rain really impedes HPM propagation with increasing frequency.

2.2 HPM penetration into the target

When the HPM beam reaches the target its field interacts with the outer structure of the target and induces transient currents and charges on the target's surface. For penetrating into the interior the HPM energy can use two different generic coupling paths, front-door coupling and back-door coupling.

Front-door denotes penetration through intentional electromagnetic coupling paths, such as communication antennas, radar antennas or altimeters. If unprotected these coupling paths provide easy penetration at in-band frequency and from main lobe direction. But most radar sets, for example, have special protection devices, which are to limit incoming signals to a safe level in order to protect the sensitive receiver from strong reflections of its own transmitter. Such protection devices can only be overcome by very fast rising HPM pulses whose front part can pass the protection device before it is fully functioning.

Back-door coupling means penetration through unintentional coupling paths like all kinds of apertures (windows, slots, seams) or improperly shielded wires. The transient currents and charges produced on the outer surface by HPM illumination conduct or induce in turn new currents in the lines between electronic subsystems as well as in the shorter lines inside of electronic devices down to the conductors in printed circuit cards. Here the HPM-generated transients interfere with the signal processing of the target's electronics and may upset or even destroy individual components.

2.3 HPM effects on target

The various potential effects of an HPM attack on an electronics-rich target can be categorized into a hierarchy of effects, which require increasing power density on target.

2.3.1 Disturbance

Derangement of mission-critical tracking, guidance or control loops of autonomous platforms, impairment of microwave sensors (radar, altimeter, navigation, IFF) or picture and audio interference. One can distinguish interference lasting only during illumination from functional disturbance which needs some recovery time after the end of the illumination to heal by itself. Even without setup or damage, disturbing a target's electronics can spoil its mission if the disturbance can be maintained as long as required by the tactical situation or if it triggers an irreversible development like breaking the target lock-on of an attacking missile.

2.3.2 Upset

Malfunction, functional failure or impairment, like non-decaying oscillations induced by HPM illumination in guidance and control loops, computer crashes, loss of critical data or disordered digital control sequences which are often caused by single pulses which hit the electronics in short time windows of particular susceptibility. The return of the target system to normal functioning requires the intervention by an external operator or by special safeguard procedures to reload programs or reset registers, procedures, computers etc.

2.3.3 Damage

Failure or defects of electronic devices, computers etc, which are caused by sufficiently strong HPM irradiation will require hardware, software or firmware replacement to repair the system. A common cause of such defects is the damage to electronic components caused by a strong HPM irradiation through back-door or front-door coupling. For components one may distinguish different damage mechanisms:

- Overheating - occurs when the HPM-induced energy arriving at component level is still sufficient to cause melting in capacitors, resistors or in PCB conductors
- Overvoltage - when the voltage of the HPM-induced transient exceeds the semiconductor barrier threshold, a break-through may occur between two conductors or between a conductor and a semiconductor junction in an IC
- Indirect damage - as a latch-up which occurs when the HPM-induced signal fires a parasitic thyristor within a semiconductor component and this thyristor remains conducting even after the transient trigger by sucking energy from the system's energy supply.

As indicated by the above damage descriptions, different types of damage are caused preferentially by different kinds of HPM illumination. It should be no surprise that such different types of HPM radiation require different types of HPM generators, including continuous wave (CW) and pulsed power generation. This is one of the reasons why the HPM source research continues along a wide front.

2.4 Various scenarios

In this chapter we compile a collection of scenarios to illustrate the broad range of potential military and related applications of HPM. These scenarios mainly serve the purpose to discuss the possibilities, advantages and limitations of HPM weapons in typical situations rather than to predict the characteristics and capabilities of future weapon systems. All of the following scenarios originate from proposals in the open literature or from discussions in the HPM community. We classify our scenarios into four broader categories.

3 Self-Protection Scenarios

3.1 Self-Protection of Large Ships against Attacking Missiles

HPMWs attacking the guidance and control of approaching cruise missiles for the last km's could be part of a self-defence suite of large ships. A recent study considers a system of large phased arrays of ultra wide band (UWB) sources for the future defence of nuclear powered aircraft carriers. [3.3]

3.2 Self-Protection of Large Aircraft against Attacking Missiles

Transport aircraft face an enormous threat by the spreading of surface-to-air (SA) and anti-aircraft (AA) missiles. One possible defence against this threat is the use of HPM sources to disable the guidance and control functions of the approaching missile at distances of several hundred metres.

3.3 Self-Protection of Fighter Aircraft against Attacking Missiles

Similar HPM pods could also be intended for the self-defence of fighter aircraft.

3.4 Self-Protection of Military Units Against Intelligent Ammunition

The special electronic counter-measures (ECM) devices already used could be supplemented by HPM devices, which could disable more general types of intelligent ammunition by back-door attacking their homing phase.

4 Attack Scenarios

- Suppression of Enemy Air Defence (HPM SEAD):
- HPM-Attack of C3I Facilities:
- Air Defence of High Value Targets:
- Tactical Air Defence in the Battle Field:
- HPM-Attack On Low-Earth-Orbit Satellites From A Fixed Ground Station:

5 Non-Lethal Applications of HPM

- Non-Lethal HPMW Against Hostile Crowds:
- Stopping of Motor Vehicles:
- Non-Lethal Self-Defence of Ships in Foreign Harbours:
- Surveillance of Coastal Waters:
- Suppression of Radio Communication in Riot Situations:

6 Use of HPM for Terror and Sabotage

- Electronic Attacks Against Airplanes During Take-off or Landing:
- Upset the Traffic Control of Railways:
- Electronic Attacks Against Civilian Infrastructure:
- Electronic Attacks Inside Buildings:
- Sabotage of Weapons or IT-Equipment in Depots or During Transport:

7 Status of the Technology

7.1 International

The U.S., France, U. K. and Russia are the main players in this technology. Russia advertises sources that can be bought off the shelf. From the U.S. also, it is easy to buy sources with peak power ranging into 100's of Megawatts. The information on whether any of these nations are deploying these sources as weapons for any of the scenarios mentioned above is classified and is not shared. One exception is the Non-Lethal HPMW against hostile crowds. This is advertised in the U.S. and is available off the shelf. In the U.S. the main player is the Phillips Air Force Laboratories at Albuquerque, NM.

Fig 3 U.S. High Energy Test Facility in Albuquerque

Fig 4 U.K. Portable HPM Source (Orion)

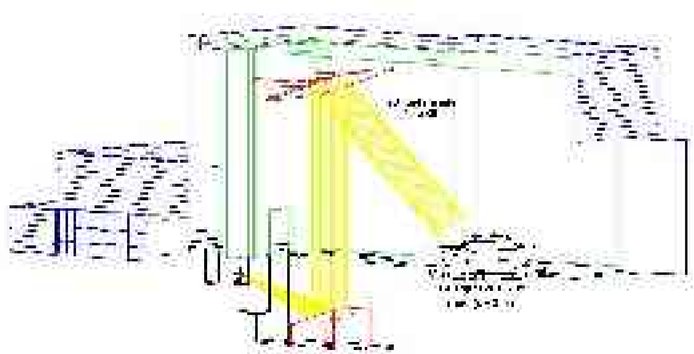

Fig 5 France High Power Microwave Facility

7.2 National

DRDC Ottawa is the only player in Canada in this regard. The HPM facilities are very small and under-funded compared to any of the main players in other countries. The 100 MW source has not been operational since its acquisition mainly because of the lack of funds. A minimum of a million dollars needs to be spent in upgrading facilities to do the HPM research to be able to guide a contractor to build a HPMW weapon, which could be deployed for some of the scenarios mentioned above. A bilateral agreement with one of the nations after upgrading the facilities will be of definite help. At the moment we are being left behind other nations in being able to use this technology.

7.3 Possible Application and Estimated Window of Introduction

There is very little capability in Canada to be able to develop HPM sources. The only possible contribution that can be made is buying components from the U.S. or another country and using them to develop the weapons for particular scenarios in consultation with the CF.

7.3.1 CF Client Perspective

The CF can benefit a great deal from the availability of this technology. For example the Navy could use a HPMW for stopping fast attack craft. The devices can be made highly directive. For example a suitcase-sized device can be easily designed to give a few degree wide HPM beam and can be used for stopping a selected car on a highway or upsetting a computer many metres away. Protection against incoming missiles by upsetting the electronics is a possible application. Other applications mentioned above are: Air Defence of High Value Targets, Tactical Air Defence in the Battle Field, Non-Lethal Self- Defence of Ships in Foreign Harbours and Surveillance of Coastal Waters.

7.3.2 Ethics

Although the peak fields from these sources are very high, the duration of the pulse is very short. As a result, the total amount of energy deposited in a particular time is within Health Canada guidelines.

7.4 Perspective of the Canadian Military client

There is a fair amount of interest from the Canadian military client. There is interest in a HPM weapon aboard the Canadian Patrol Frigate that can be used against an incoming missile.

8 Recommendations

As a first step toward coordinating CF requirements with the DRDC R&D program, there needs to be an exchange of information with the representatives of army, navy and air force. It is proposed that DRDC project manager and thrust leader meet with the appropriate representatives to brief them on the R&D program and its delivery mechanisms. Representatives of army, navy and air could provide an overview of their needs and strategic directions and if possible the research areas in which DRDC could play a role. This should be followed up by a number of visits to be able to come to an understanding of what the requirement is for the program and the HPM research facility. DRDC should then provide funds and resources to upgrade the facility to a level where it can play a role in exploiting HPM technology for CF purposes.

Annex E. Acoustic Weapons

By

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September 2004

1 Background

Much has been said in the open literature about acoustic weapons, about applications ranging from the use of loud annoying sounds (the siege of general Noriega at the Vatican Embassy, or wearing out Taliban prisoners resistance with hard rock and heavy metal music) to the sickening and deadly effects of infrasound, and even wild claims about the possibility of mind control. However, a large part of the available documentation seems to originate from the imagination of conspiracy theorists, esoterists and overly enthusiastic military writers. The existence of many of the most frequent references and events reported by these writers is impossible to ascertain and in many cases doubtful, and their interpretation of acoustic properties often faulty. Reliable references are much harder to come by, and do not necessarily convey the same message.

The idea of using sounds in warfare goes back to antiquity. The earliest known description of acoustic warfare are found in the mythic Veda's of old Hindu literature, which describe blazing sun-like arrows triggered by sound and speak of armies destroyed by sound weapons, and in the Bible, where the trumpets of the army of Israel allegedly destroyed the walls of Jericho. More prosaically, the use of war cries, drums and other noisy devices to unsettle the enemies can also be considered as a form of acoustic warfare. Closest to our times, it is said that the Nazis used infrasound to affect the mood of crowds during political rallies and also carried research in acoustic weapons prior to WW2 [1].

Sound is a pressure wave that propagates though gas, liquids and solids, carrying mechanical energy. The distance and direction of propagation depends on the sound properties (frequency, wavelength and intensity) and those of the media though which it propagates. The average human senses and processes sounds that range from 20 Hz to 20,00 Hz (the audible range). Inaudible sound waves from 0 – 20 Hz are labelled as "infrasound" and those beyond 20 000 Hz as ultrasound.

For the purpose of this study, acoustic weapons are defined as devices that are used to aim mechanical energy at a target using sound waves and air pressure as carriers.

1.1 Blasters (audible range)

These are probably the less sophisticated of the acoustic weapons described in the literature. They rely on sheer decibels level and annoying sounds to deter or repel people. Their pain threshold is at about 135db [2]. Depending on the intensity of the sound, the target effects may range from hearing interference, performance degradation, pain, temporary and permanent hearing losses and tissue damage. Such systems have been reportedly used in psychological warfare operations. While such devices may be efficient in crowd control against the less convinced demonstrators, their actual effect against dedicated, well-trained individuals wearing ear protection would likely be minimal. The proponent of this technology argue that at least it allows to single out the serious opponents so they can be dealt with using more efficient weapons if necessary, without endangering the rest of the crowd.

A few systems are already available commercially. Scientific Applications & Research Associates, (SARA) Inc. advertises the Directional Sonic Firehose, a system that is said to focus intense sound to a selected target, creating a non-lethal deterrent at ranges in excess of 1 km. Man-portable prototypes are now operating at SARA's labs [3].

General Dynamics Armament and Technical Products (GDATP) and American Technology Corporation are offering the High Intensity Directed Acoustics (HIDA™), described as a non-lethal, scalable-effects acoustic device. Through a 33-inch loudspeaker, this 40-lbs system emits an audible acoustic signal providing 154 decibels (dB) of sound at 1 meter from the source, 120 dB at 60 meters, verbal communications at 500 meters and warning tones at 1,500 meters. The companies claim that depending on range, power output, frequency, tonal patterns and exposure time, HIDA's effects may range from confusion and reduction in cognitive abilities to debilitating hearing discomfort [4]. This is consistent with the effects reported in the literature for such sound intensity.

1.2 Infrasound and low frequencies acoustics

The average human senses and processes sounds that range from 20Hz to 20,00 Hz (the audible range). Inaudible sound waves from 0 – 20 Hz are labelled as infrasound and those beyond 20 000 Hz as ultrasound. Infrasound occurs in many natural phenomena such as thunder, earthquakes, erupting volcanoes, and tidal waves. It is also often generated by heavy industrial machinery and it has to be taken into account by civil engineers in designing certain structures. It can propagate over large distances through solid matter such as soil, rock and concrete. However, it naturally disperses in all directions, rapidly loosing intensity.

Like other sounds, infrasound and low frequency sound can be generated mechanically by oscillating devices (essentially, loudspeakers) or by modulating a continuous gas flow (whistles and sirens). See paragraph on Vortex rings below.

Both infrasound and ultrasound can be perceived through the body cavities. Theoretically, infrasound and low-frequency acoustic oscillations can be used to induce resonant vibrations that will affect the whole body or specific internal organs and body cavities while still remaining inaudible. To achieve this effect, the sound frequency must be closed or matched to the resonant (also call natural) frequency of the targeted organ(s). For example, 7 Hz was measured as the flesh resonant frequent frequency, 19 Hz for the eyeballs. The resulting effect is also a function of the duration as well as of the intensity of the sound. The effects of infrasound on humans were studied in a few countries, in particular the US and Russia. Reference 2 presents a summary of these effects reported in the open literature that are reproduced in the following tables.

Table 1 Ref. [5] presents symptoms/effects on humans as a function of the sound frequency

Nausea, motion sickness	10^{-1}-10 Hz
Beginning of resonance in organism	10-10^{2} Hz
Disturbance of breath and speech	10-10^{3} Hz
Loss of visual acuity	10-10^{2} Hz
Loss of balance	10^{-1}-10^{2} Hz
Disturbance of movement coordination	10^{-1}-10^{2} Hz
Negative effects on cardiovascular system	10-10^{3} Hz
Heating of tissues, destruction of cells	10^{3}-10^{6} Hz.
Friction between internal organs	200 Hz
Vibrations of jaw about skull	100-200 Hz
Skull vibrations	400 Hz

Table 2 presents the symptoms/effects described by various references for infrasound and low frequency oscillations as a function of sound intensity [6] [7] [8].

Incapacitation, Death potential	Very high power[7] (170-190 dB for 10 seconds [5])
Uncontrolled behavior, consternation, sickness, headache, internal organs affected (diarrhea and urination)	High power[7]; 130-150 dB for 10 seconds[6]
Informational influence, annoyance, irritation, interference with performance, auditory system affected	Low-Medium power[7]; <130 dB for 10 seconds[5]; 130-140 dB[6]

Since the mass, size and mechanical properties of internal organs, tissues and bones may vary extensively from one individual to the other as a function of size, age, gender and fitness, and because the physiological reactions of human to sound frequency are very selective, individual reactions and consequences should likely vary from subject to subject. What would be an effective NLW against a trained, healthy individual may prove fatal for an infant or an elder, while a NLW tuned not to fatally harm the weakest might be relatively inefficient against the fittest.

Being able to measure the effects of infrasound and low-frequency acoustics on humans and structures is one thing, but to actually "weaponize" the technology has proven to be much more difficult. An infrasound acoustic weapon shall provide accurate aiming, efficient and adjustable range, controllable target effects and weapon servants' protection. For logistic purposes, more mundane considerations such as weight and size must also be taken into consideration. Because of the inherent properties of infrasound, such a weapon would be cumbersome, and since infrasound are dispersive and non-directional, especially in the air, aiming it accurately at targets while protecting one's own troops against its effects may prove difficult if not impossible [9] [10]. It is theoretically possible to combine higher frequencies emitted by two different sources to generate infrasound at the target, thus reducing the size of the system. However, it would be relatively easy to shield against such a system. For example, the hypothetic British system operating at 16 000 Hz and 16 002 Hz described by B. G Nichols in his essay "Deadly Vibrations - a brief history of sonic warfare" [11] would most likely be hampered by simple clothes, be only effective against bare skin, and have a range of only a few tens of meters. A recent study on NLW carried out by the US National Research Council (US NRC) of the National Academies on behalf of the US Marines Corps [12] confirms the existence of past R&D programs on acoustic weapons including infrasound weapons and reports that these programs were unsuccessful for reasons similar to those mentioned above. The same study also concludes that "no extra-aural bioeffects that significantly affect the adversary behavior" were demonstrated.

1.3 Ultrasound

Unlike infrasound, higher sound frequencies, hence ultrasound can form into a beam. At low power, ultrasound is used in materials non-destructive evaluation and in non-invasive medical therapies and dentistry where it's inaudible, and therefore non-intrusive attributes are advantageous. However, at the higher power level required for a weapon, propagation soon becomes non-linear, and is highly dependent on atmospheric conditions, thus limiting the effective range and the ability to control the effective power level at the target.

When used as a weapon, ultrasound are said to provoke possible diffuse psychological effects, pain, surface tissue damage, tissue destruction [13]. Weapons emitting sound near the ultrasonic range above 12,000 Hz are reported to induce an intolerable combination of pain, confusion and fear exceeding an individual's ability to reason and risk further aggression, without being detected aurally [14]. However, the US NRC report on NLW [15] reached the same conclusion for ultrasound as for infrasound regarding their demonstrated efficiency.

1.4 Vortex Ring

A vortex ring is defined as "a stable perturbation in a fluid that takes the form of a torus in which the flow rotates in the section of the torus so that the pressure difference between the inside and outside of the torus balances body forces. The best-known vortex ring is a smoke ring." [16] Vortex rings occur naturally in dust devils and thermal puffs, and are even used for propulsion by some fish species. The phenomenon is used by engineers for fuel atomization in internal combustion engines, and is well known to aerodynamicists. The creation of vortex ring around helicopter main rotors at landing is a potentially catastrophic situation responsible for several crashes.

In NLW applications, a vortex ring is used to transport a mechanical impulse to a target. More plainly, such a weapon would literally use a directed blast of air to knock someone off his/her feet. Target effect is dependent on the impulse generated. The effect could be amplified by including tear gas or other chemicals in the gas generator.

Two modes of generations can be used. First, a single blast of gas expelled from a gun tube. The blast can be generated using a pyrotechnic charge or compressed gas. Second, a continuous gas flow can be modulated to generate a train on vortex rings. (see fig. 2)
In the both case, as the gas flow is expelled from the tube, the outer layer of this moving gas cylinder is dragged backward relative to itself by the still atmosphere until a large part of the flow swirls into a spinning doughnut of gas, the vortex ring. See fig. 1 below.

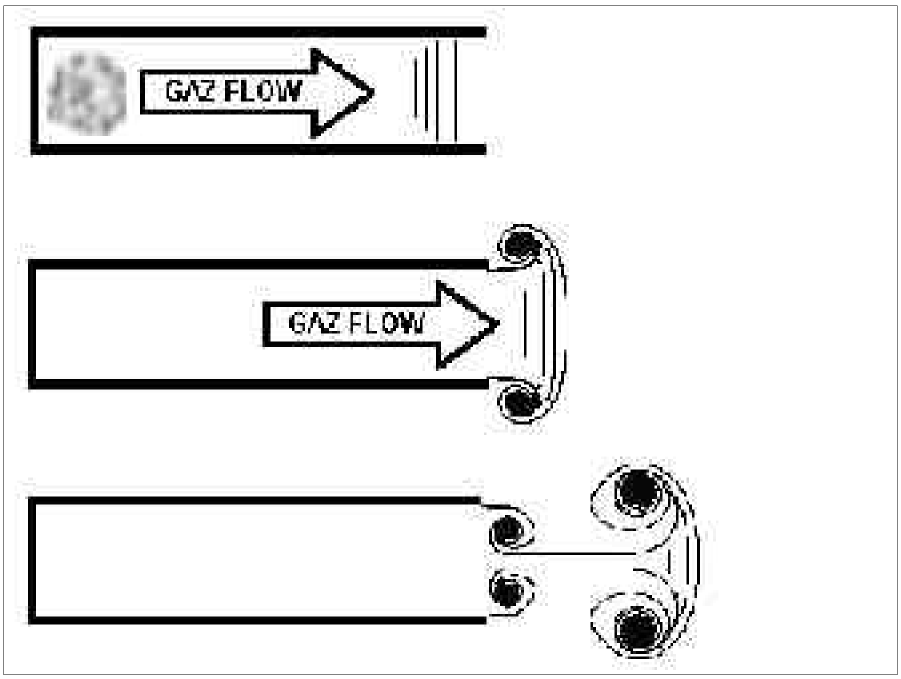

Figure 1. Formation of a Vortex ring.

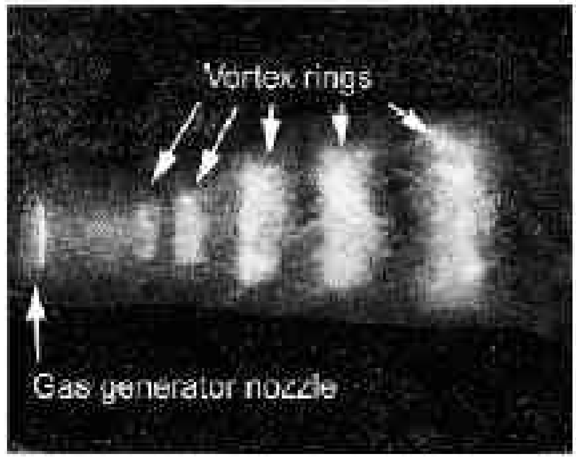

Figure 2. Train of vortex rings generated by a continuous gas flow [17]

Most references reviewed consider that this technology is still at the R&D stage. In the UK, there is a basic research program to investigate the physics of vortices. Through Modelling and Simulation, this group was able to demonstrate vortex stability at ranges up to 48 meters [18]. In Russia, the Bauman Moscow State Technical University reports using continuous flow vortex generators to produce high intensity sounds at 65 meters, ranging from 262 Hz to 718 Hz, and sound pressure level from 143 to 164 dB [19]. The authors, while considering that the technology is promising, admit that the approach is still empirical and that a lot remains to be explained.

In a paper presented by ICT researchers [20], an **I**nfra-**P**ulse-**G**enerator that combines high noise level with periodic shock waves and propagating vortex rings is mentioned. According to the same paper, the impact of propagating vortex rings is poorly investigated. This Infra-Pulse generator operates in three modes, one of which generates vortex rings at a frequency around 15 Hz, and can be used to transport irritants (gas or particles) to the target [21].

In the US, DoD does not fund this technology anymore, because previous efforts to develop the technology did not demonstrate a sufficient range.

Single blast vortex ring guns have been developed, such as the SARA's Vortex Launcher, which is described as follows [22]: "a supersonic vortex of air hits its target at about half the speed of sound with enough force to knock them off balance. The vortex feels like having a bucket of ice water thrown into your chest. For use in riot or crowd control to stop the crowd from advancing without doing them any harm".

SARA's Vortex Launcher

TRES Corps Weapons [23] advertises the PP-100m Puffer, which is said to generate a 0.7-1.8 kilojoules impulse. The reference does not provide any information about the effective range.

1.5 Pyrotechnic sound devices

Devices known as flash/bang or stun grenades are available on the market. These are designed to momentarily startle, disorient, shock the target, or make it flee, using flashes, intense sound and overpressure. Their effects and duration are dependent on the intensity of the sound and/or flash and on their duration. They can be hand tossed or delivered by a grenade launcher. They still present the risk of injuring the target if dropped to close (hearing loss, eye damage, lung damage and burns).

2 Status of the acoustic weapons technology

2.1 International

While the US government appears to have stopped or significantly downsized its support to acoustic weapons technology after extensive testing have failed to demonstrate their usefulness, R&D efforts continue in US industry and in several European institutions. As indicated in the previous paragraphs, several acoustic weapons and devices are now available commercially on the international market, although in most cases, a careful evaluation by the buyer would be advisable in regard of the performance claimed by the manufacturers.

2.2 National

To the author's knowledge, there are no research program, developer or manufacturer of acoustic weapons in Canada.

3 Expected applications and time of availability

Depending of the device used, the most likely applications for acoustic weapons are warning and deterrence, crowd control, psychological operations and swat team type of operations. While devices using several of the technologies described in the previous paragraph are available on the market today, blasters and pyrotechnic devices are probably the only demonstrated technology. According to the US NRC report on NLW [24], only flash/bang grenades have been successful in causing reliable non-lethal effects.

Vortex ring generators have not yet been fully investigated and may prove to be an interesting technology in the coming years.

4 Recommendations

At this point in time, DRDC should limit its effort to technology watch as far as acoustic weapons are concerned. Vortex ring generators appears to be the only area where useful development may happen in a foreseeable future, and so far there is no clear demonstration of their potential. Vortex rings are essentially an aerodynamic phenomenon for which the basic expertise is available within DRDC and the NRC. Should the Canadian Forces decide to acquire blasters and flash/bang grenades, their effects on humans should be carefully evaluated to develop safe rules of engagement and avoid permanent injuries to targets. Experts in industrial noise safety standards would likely be the best source of expertise in that regard and the need to develop a DRDC dedicated in-house expertise is unlikely.

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Annex F. Non-Lethal Research and Development for Defence R&D Canada

By

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DRDC Programs

November 2003

1 Introduction

The main role of defence research and development (R&D) is to provide military forces with the essential knowledge to permit them to anticipate and harness the capabilities inherent in current and emerging technologies. One of the means by which Defence R&D Canada (DRDC) achieves this is through Project 20ab – Expert Assessment of Emerging Technologies. This is a standing Director Science and Technology Policy (DST Pol) project designed to conduct short, focused studies in order to assess emerging technologies in the Canadian defence context.[1] The Non-Lethal Weapons: Opportunities for R&D study was commissioned by the Technology Assessment Working Group (TAWG) under this project to examine the status and potential capabilities of technologies involved in Directed Energy Weapons (DEWs) and Non-Lethal Weapons (NLWs). This paper supports the NLW aspects of this Study.

The Non-Lethal Weapons: Opportunities for R&D study is particularly timely. It is evident from operational experience, as well as international studies, that there is a growing need for armed forces, especially the Land Forces, to understand and acquire NLWs. Like its allies, the Canadian Forces (CF) are being deployed more often in situations where NLWs (which can include some Directed Energy technologies when used at the lower end of the power spectrum) would be of significant value. The great majority of these deployments have been and will likely continue to be land-based and urban. In response to this growing demand, DRDC should identify the type of focused DRDC NLW R&D activity that is required to meet CF non-lethal capabilities requirements.

2 Aim

The aim of this paper is to recommend the near-term NLW R&D that DRDC should conduct over the next decade in response to emerging CF NLW requirements.

3 Scope

This paper will cover the following areas as seen at the time of writing in November 2003:

- the Canadian NLW definition;
- the NLW Technology Taxonomy;
- the status of CF NLW policy;
- the legal status of NLW employment;
- ethical considerations in NLW R&D;
- naval NLW requirements;
- air force NLW requirements;
- Land Force NLW concepts, doctrine and requirements;
- relevant international NLW studies;
- technological barriers facing NLW R&D
- the current level of DRDC NLW expertise;

[1] Project Objective in CPME Project Summary for FY 02/03.

- a proposed course of action;
- conclusions; and
- recommendations for near-term NLW R&D.

4 NLW Definition

The CF defines NLWs as:

> Weapons, munitions, and devices that are explicitly designed and primarily employed so as to incapacitate personnel or materiel, while minimizing fatalities, permanent injury to personnel and undesired damage to property and the environment. This definition does not include information operations (e.g. jamming, psychological operations, etc.) or any other military capability not designed specifically for the purpose of minimizing fatalities, permanent injury to personnel, and undesired damage to the environment, even though these capabilities may have non-lethal effects (e.g. smoke and illumination).[2]

This definition is very similar to that of NATO and the US. In law enforcement fora "Less-Lethal Weapon" is more often used than NLW. The term "Non-Lethal Capability" is also found to describe non-lethal requirements. It recognizes that the solution to a non-lethal deficiency may not always be a weapon. For example, the psychological response of targeted individuals (be they by themselves or operating equipment) or the physiological injury inflicted by a weapon might create a greater problem for the military force in either the short or longer term. In such cases, it would be more productive to use "Non-Lethal Techniques" which are essentially specialized skills designed to resolve problems through non-violent action. They are not meant for every situation and where they are used and fail, NLWs will likely be the next step in the escalation of force.[3] This paper will use the term NLW to include non-lethal and less-than-lethal weapons, capabilities and techniques where the context makes sense.

5 NLW Technology Taxonomy

Several taxonomies of NLW technologies have been produced by various organizations and study groups. The NATO SAS-035 NLW Technology Taxonomy which is based on the one produced by the US Joint NLW Directorate[4] is attached at Annex A. It consists of electromagnetic, chemical, acoustic, mechanical and kinetic, and ancillary technologies. The taxonomy illustrates the breadth of the technologies that could be investigated in NLW R&D. With limited resources, some prioritization or concentration of R&D effort is necessary if significant progress is to be made in such a wide technology field. A factor in this prioritization is the R&D potential of each technology group. Not all are equal. The mechanical and kinetic technologies are well developed and not surprisingly, are the most commonly used in NLWs now available. NLWs based on these technologies are perhaps

[2] B-GL-300-007/FP-001 (1999-02-09), Firepower, page 105, paragraph 2.
[3] See TTCP document DOC-WPN-AG-17-10-2001. WPN Action Group 17 identified Non-Lethal Techniques as a response to some situations at a Joint WPN/HUM/JSA Workshop on the Psychological Aspects of NLWs in April 2001.
[4] The US DOD authorized the Joint NLW Directorate in 1996 under the executive agency of the US Marine Corps. Its primary function is to acquire available technology that can be fielded quickly.

approaching their developmental limits from a science and technology point of view. Directed energy (i.e. electromagnetic and acoustic) and chemical (i.e. agents that affect the central nervous system or operation of equipment, subject to the legal constraints) technologies, on the other hand, have greater growth potential.[5]

6 CF NLW Policy Status

At this point in time, there is neither an approved nor draft CF NLW Policy other than that contained in the Crowd Confrontation Operations manual (see below). The reason may be that few issues have arisen that warranted the formulation of an overarching Departmental policy. The circumstances, conditions, degree, manner and limitations within which either deadly or non-deadly (e.g. NLWs) force can be used are defined by the Rules of Engagement.[6]

The CF has, however, accepted the NATO NLW policy.[7] The NATO policy, which is attached at Annex B, is a high level document that provides the guidance for Alliance members to develop and employ NLWs. It also establishes a common basis for international collaboration and operational interoperability that should be a factor in R&D and equipment procurement.

A document that is perhaps more relevant to near-term R&D is the new Crowd Confrontation Operations (CCO) manual.[8] It represents a new CF capability requirement that has stemmed from the changing nature of CF peace support and crisis response operations. This doctrine and training manual is more specific than a policy document might be and is consequently a useful guide for CCO related NLW R&D. It is a Canadian statement of how the CF will employ NLWs in this particular type of operation, be it NATO sponsored or not, at the operational and tactical levels. The CCO manual makes the following points relevant to NLWs.

a. The CF is to be equipped with non-lethal capabilities in international and possibly domestic (i.e. when specifically ordered) operations where the CF may assume crowd confrontation duties.

b. The aim in providing the CF with non-lethal capabilities for CCO is to:

   - assist in mission accomplishment,
   - enhance force protection, and
   - assist in preserving life by reducing the need to resort to lethal force.

c. It is recognized that the use of NLWs may result in fatalities.

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[5] Preliminary results from NATO SAS-040 Multi-National Exercise, November 2003.
[6] B-GG-005-004/AF-005 Use of Force Manual, Chapter 2, Section 3.
[7] NATO Press Statement, 13 October 1999. As a NATO member Canada accepts this policy in NATO operations.
[8] B-GJ-005-307/FP-90 Unique Operations – Crowd Confrontation Operations. Armed Forces Council approved this document on 21 May 2003.

d. NLWs are to be backed by the capability to use lethal means when authorized and justified.

Notwithstanding the absence of a formal Canadian NLW policy, the CF clearly intends to acquire and employ NLWs for CCO. As this is a new CF requirement, DRDC may have to build a greater NLW expertise than it currently possesses.

7 Legal Status of NLW Employment

All CF military operations, be they domestic or foreign, in peace or in war, are governed by national and international law.[9] The Law of Armed Conflict,[10] Use of Force[11] and CCO manuals describe the legal principles for the use of force in these operations. The most relevant legal principles to NLWs (i.e. the application of non-deadly force) are:

a. Minimum Force. The use of authorized force, up to and including deadly force, must never be more than what is necessary and reasonable based upon the prevailing circumstances. Any force used must be limited to the degree of intensity and duration, reasonably necessary to achieve the objective for which the force is used and no more.

b. Proportionality. Only a response proportionate to the perception of the level of threat is justified. Any force used must be limited to the degree of intensity and duration, reasonably necessary to achieve the objective for which the force is used and no more.

c. Collateral Civilian Damage. Collateral damage, which consists of unintentional injuries to people or damages to structures near targets, shall be minimized.

d. Application of Force and Disengagement. The application of force shall cease when the imminent use of force or the hostile act stops or when it is reasonably believed that it longer constitutes a threat.[12]

These documents clearly indicate that the use of NLWs is authorized for use by the CF provided the legal principles are followed. The implication, however, is that to determine whether these principles are either followed or contravened the CF must first understand the probable effects of its NLWs. This understanding does not necessarily come easily. Foreign studies have indicated that NLW effects claimed by various NLW manufacturers have not always reflected the weapon's actual performance when measured in scientifically controlled tests.[13] Even if the weapons effects data are contained in the technical data package procured

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[9] For a description of the international law applicable to NLW employment see the TNO document Legal Assessment NLW dated 2 June 2002 provided to the NATO SAS-035 Study. This document is a Netherlands interpretation of international law.

[10] B-GG-005-104/FP-021 Law of Armed Conflict at the Operational and Tactical Level, dated 13 August 2001.

[11] B-GJ-005-501/FP-000 Use of Force Manual in CF Operations, dated 1 June 2001, (Revision 1). See Chapter 1, Section 4 for use of force in peacetime and during armed conflict.

[12] B-GJ-005-307/FP-90 Unique Operations – Crowd Confrontation Operations, Chapter 1, Section 5.

as part of the NLW project, it would be prudent for the CF to at least verify and maintain a data base of weapon performance for those NLWs in Canadian service.

Nevertheless, the debate continues over the legality of some NLW technologies, particularly chemical and biological NLWs. There appears to be a legal paradox emerging in which international treaties and protocols were developed at a time when the non-traditional military roles in peace support operations or the advances in non-lethal technologies were not anticipated. For instance, the use of chemical and biological weapons is prohibited and therefore, strictly speaking, so is the development of a non-lethal application to reduce casualties. Riot control agents are legal for domestic use by police, but not by soldiers in wartime. In addition, the allegation is sometimes made that NLWs will be used for torture or suppression of legal dissent, although the developer or user's intent is the legally determinant factor. The argument has been made that perhaps the applicable treaties should be revisited and where applicable changed to meet today's circumstances.[14] NLW R&D can assist this debate by providing scientific data on the effects of the various non-lethal technologies.

8 Ethical Considerations in NLW R&D

Any R&D activities involving participation by human subjects must respect the ethical principles laid out in research protocols and constraints imposed by law.[15] Established procedures exist in DND to balance the risk to the person participating in the research with the benefit to the CF of the information gained.[16] This requirement has always been an issue in weapon development and will remain so for NLWs.[17] The welfare of the individual participants will certainly always take precedence over the value of effects data to the CF. The collection of human target effects data for NLWs is further complicated by the reluctance of medical organizations and medically trained personnel who normally work on health and safety issues, to advise on better ways of incapacitating or inflicting pain in people.[18] The R&D community must accept that ethical considerations may curtail the method of experimentation used and therefore, data collected.

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[13] The Attribute-Based Evaluation of Less-Than-Lethal Extended Range Impact Munitions, which was published by the Applied Research Laboratory, Pennsylvania State University on 15 February 2001 is a study on the effectiveness of NLWs normally employed by police forces. The authors are Dr John Kenny of the Applied Research Laboratory and Capt Sid Heal and Capt Mike Grossman of the Los Angeles Police Department.

[14] John B. Alexander, Non-Lethal Weapons: Still Relevant?, presentation given to Janes Less-than-Lethal Conference, September, 2002.

[15] Human Subject Participation in Research Projects: Ethical Considerations (With Emphasis on Procedures Conducted at DRDC Toronto) by Dr Jack P. Landolt, Canadian Military Review, Vol 3, No 4 Winter 2002-2003, pages 27-32.

[16] For a description of some of the issues involved with the potential misuse and therefore concern with non-lethal technologies see An Appraisal of Technologies for Political Control which was a Scientific and Technology Options Assessment published in two documents by the European Parliament. There are two reports, one dated January 1998 and the other September 1998.

[17] NATO Document AC/259-D(2001)5(1) Road Map for the Development and Use of Non-Lethal Weapons Effective Engagement EE2(I), 1 February 2001, pages 7-8.

[18] HFM-073 Briefing to SAS-035 Meeting 15 May 2002.

9 Naval NLW Requirements

The Canadian Navy has identified general anti-materiel NLW capability requirements for constabulary naval operations where the objective is to stop a ship at sea. The Navy Blueprint recommends that R&D be conducted on non-lethal means of disabling fleeing ships or craft of all sizes.[19] Possible NLW types could be mechanical devices that snag propellers and running gear, chemical embrittlements that weaken a ship's structure, sonic systems or other means to stop a ship with minimal risk to the crew. The US Navy has similar NLW requirements.[20] Anti-personnel NLW naval requirements have been identified for land-based CCO operations in dockyards and for boarding parties.[21]

10 Air Force NLW Requirements

The Canadian Air Force is preparing an Aerospace Capability Framework that will articulate its capability assessments and goals.[22] It is still in draft format at the time of writing (i.e. November 2003). It is therefore premature to state specific air force NLW requirements. It would appear, however, that the air force might explore non-lethal applications in aerospace operations particularly in air delivered anti-material NLWs.

11 Land Force NLW Concepts, Doctrine and Requirements

The Canadian Land Force has identified the need for NLW capabilities in its concepts, doctrine and equipment requirements, which are by far more mature and detailed than either the navy or air force. This should not be surprising as the most probable NLW scenarios for the CF will be urban and land-based.

At the Land Force conceptual level, the Director Land Strategic Concepts (DLSC) assessed the importance of NLW concepts during Exercise Urban Challenge, which was set in 2025. It concluded that regardless of the technical sophistication of a future land force, there was a critical requirement to possess individual and collective NLWs or effects.[23]

The Director of Army Doctrine (DAD) has described the overarching Land Force NLW doctrine in the Firepower manual.[24] DAD has also described NLW capability requirements in the Final Report of the Land Force Urban Operations Working Group,[25] which was published and endorsed by the Combat Development Board in 2002. It focuses at the operational level of command and identifies 52 capability requirements applicable for urban operations out to approximately 2020. The capability requirements were in a matrix that identified potential solutions against the PLOTED (i.e. Personnel, Leadership, Organizations, Training,

[19] The Canadian Navy's Above Water Warfare Blueprint to 2010, pages 33-36.
[20] An Assessment of Non-Lethal Weapons Science and Technology produced by the National Academy of Sciences, National Academies Press, Washington, D.C. 2003, page 2.
[21] B-GJ-005-307/FP-90 Unique Operations – Crowd Confrontation Operations.
[22] CAS Planning Guidance 2003, page 2.
[23] Future Army Experiment, Operations in the Urban Battlespace, Fort Frontenac, May 2002, page 12.
[24] B-GL-300-007/FP-001 (1999-02-09), Firepower, Chapter 5.
[25] Land Force Urban Operations Working Group Final Report, 29 May 2002. This Working Group was authorized by DGLS in a Staff Planning Directive in June 2001. The Working Group was chaired by DAD 4 (Manoeuvre) and had representation from the NDHQ based Land Staff, LFDTS, the Combat Training Centre and DRDC.

Equipment, Doctrine)[26] capability package for each requirement. The Equipment column was divided into Equipment-Today and Equipment-R&D to emphasize that R&D is essential in achieving some capabilities.

The Working Group identified 52 operational level of command capability requirements. There is one specific non-lethal capability requirement and arguably seven others where NLWs could be a secondary requirement. These requirements are:

- Primary NLW Capability Requirement:
  a. apply non-lethal effect.

- Secondary NLW Capability Requirements:
  a. the ability to assess effects;
  b. identify the location, status, numbers and intent of local population;
  c. control population movement and non-combatant manœuvre;
  d. distinguish between Blue/Red/Non-combatants;
  e. conduct counter-mobility operations;
  f. create urban field fortifications; and
  g. provide individual protection.

The Working Group went beyond just identifying capability requirements by proposing potential solutions for each capability requirement across PLOTED. The Equipment-R&D column of the capability matrix listed many possible NLW solutions and is reproduced at Annex C.

The Director Land Requirements (DLR) recognizes the importance of NLW R&D in its Business Plan by providing guidance to "investigate less-than-lethal or non-lethal munitions".[27] This guidance which is provided specifically to Thrust 2N Munitions and Firepower is under review in accordance with decisions by the Army S&T Review Working Group in September 2002. The Non-Lethal Weapons: Opportunities for R&D study and this paper constitute the detail to support the review of this NLW guidance.

In addition to providing R&D guidance, DLR is also staffing a non-strategic capital project number 0278 called Close Combat Non-Lethal Systems (CCNLS) to acquire various anti-personnel and anti-material NLWs, associated ammunition, protective clothing and training equipment.[28] This project is the Canadian version of the Non-Lethal Capability Set (NLCS) being defined by NATO.[29] A list of the planned and possible CCNLS equipment and some

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[26] PLOTED was a Land Force mnemonic for **P**ersonnel, **L**eadership, **O**rganizations, **T**raining, **E**quipment, **D**octrine and was used to describe the elements required to support the fielding of a capability. It has since been replaced by the CF mnemonic PRICIE which means **P**ersonnel (Individual Training and Leadership), **R**esearch and Development and Operational Research, **I**nfrastructure and Organization, **C**oncepts, Doctrine and Collective Training, **I**nformation Management, **E**quipment and Materiel.

[27] DLR Business Plan FY 2002-2003, Table 6.1 dated 3 May 2002. This guidance has remained unchanged in the annual DLR Business Plans since 1998.

[28] Capability Initiatives Database, Project 00000278 dated 26 August 2002.

Unforecasted Operational Requirements is at Annex D. DLR plans to acquire this equipment in the following three stages.[30]

a. First Level – Basic Force Protection. This procurement consists of 16 items of personal equipment to be worn or used by the individual soldier. The weapons being procured are a wooden riot stick, high intensity lights, oleoresin capsicum (OC) or pepper spray and a standoff weapon with ammunition. The ammunition is likely to be 40mm sponge grenades, 12 gauge shotgun fin-stablilized shape rubber projectiles and 12 gauge drag stabilized sock rounds.

b. Second Level – Enhanced Standoff. This requirement is still being defined but may include larger OC dispensers and a water cannon.

c. Third Level – Combined Arms Crowd Confrontation Operations. This stage of the project is yet to be defined but will address the requirement for barriers and special purpose CCO vehicles such as an engineer tractor, a modified LAV and a "snatch" vehicle.

This project's near term horizon, especially for the first level, leaves limited scope for meaningful R&D prior to implementation. However, it identifies the technologies of interest to the Land Force, at least in the short term, and provides an opportunity to collect observations of the effects of blunt trauma weapons should they be used on operations.

The five documents described above articulate Land Force NLW capabilities that span the conceptual, doctrinal and equipment requirements levels. They indicate not only that the Land Force has a near term need for NLWs, but also is developing concepts and doctrine to expand the future use of NLWs well beyond the scenarios envisaged by the current CCO manual. This longer-term perspective provides time for the requisite R&D to acquire the necessary knowledge to advise the Land Force on future NLW effects and operational effectiveness.

12 International Studies

There have been several international studies on NLWs over the past few years. DRDC has participated in some and not in others. Participation in these international activities has kept a few members of DRDC abreast of most of the key non-lethal R&D issues. The studies relevant to future NLW R&D by DRDC are listed below and briefly described in subsequent paragraphs:

a. NATO/259 study on Non-Lethal Technologies for Peace Support Operations;

b. NATO/AGARD AR-347 Minimizing Collateral Damage during Peace Support Operations;

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[29] Interim Report AC 225/Land Group 3 Military Operations on Urban Terrain Non-Lethal Capability Team of Experts, 3 May 2003. The NATO Non-lethal Capability Set described in this report will likely evolve over time.

[30] DLR 5-5 Briefing to Land Force Combat Development Board 21 March 2002.

c. NATO RTO SAS-041 Improving Land Armaments: Lessons from the Balkans;

d. NATO/AC 225 Land Group 3 Military Operations in Urban Terrain/Non-Lethal Weapons Team of Experts;

e. NATO RTO SAS-035 Assessment of NLW Effectiveness;

f. NATO RTO SAS-040 Non-Lethal Technologies for Future Peace Support Operations;

g. NATO RTO SCI-019 Tactical Implications of High Power Microwaves;

h. NATO RTO HFM-073 Human Effects of Non-Lethal Technologies;

i. TTCP WPN Action Group 17 Non-Lethal Weapons; and

j. TTCP HUM Action Group 22 Research Designs for the Assessment of NLW Human Effects.

NATO/259 Non-Lethal Technologies for Peace Support Operations. This 1996 report describes the feasibility and utility of non-lethal weapons in peacekeeping and peace support operations. It concluded that there were NLW technologies of value although the immaturity of some made it difficult to assess their operational effectiveness. The following technologies, which are covered by the Taxonomy at Annex A, were identified as potential areas of collaboration:

a. dazzle lasers;
b. odours;
c. non-penetrating projectiles;
d. containment devices/entanglements;
e. optical coatings
f. anti-traction agents;
g. soil destabilization;
h. combustion modifiers;
i. super adhesives and binding coatings; and
j. markers.[31]

NATO/AGARD AR-347 Minimizing Collateral Damage during Peace Support Operations. This investigated various innovative means, one of which was NLWs, of attacking discrete ground targets from airborne platforms. It concluded that air delivered NLWs would provide commanders with greater flexibility such that their employment would be limited to crowd

[31] North American Treaty Organization Conference of National Armaments Directors. Non-Lethal Weapon Technologies for Peace Support Operations. Report no. AC/259-D/1967, 19 Mar. 1996. Brussels: NATO, CNAD, 1967.

control and anti-personnel tasks in a benign air environment.[32] DRDC was not a member of the study.

NATO/AC 225 Land Group 3 Military Operations in Urban Terrain/Non-Lethal Weapons Team of Experts. This on-going Team of Experts (ToE) established a NATO agreed list of material items, with description sheets, for a NATO Non-Lethal Capability Set that could be fielded by 2005. It recommended that follow-on work be conducted for standardization of non-lethal munitions and the establishment of a common method for quantification of weapon effects. DLR 5 provides the only Canadian participant.[33]

NATO RTO SAS-035 Assessment of NLW Effectiveness. This is one of the three NATO studies created by the NATO NLW Road Map.[34] This recently completed study created a viable assessment methodology that interprets and compares the effects of the non-lethal technologies with the tactical objectives of the military commander. This methodology is applicable across the NLW Technology Taxonomy to both personnel and material targets. It also supports comparisons of effectiveness between non-lethal and lethal weapons as well as aspects of electronic warfare or information operations.

The innovative contribution of the SAS-035 methodology is its approach to NLW assessment that involves:

a. the categorization of personnel and materiel target responses across seven dimensions, reflecting the effect on the target's mobility, communication, physical function, ability to sense and interpret, group cohesion, motivation, and identification;
b. the establishment of measures of target responses across the seven dimensions in terms of magnitude of the effect, the duration of the effect and the length of time taken by the target to recover; and
c. the establishment of three measures of effectiveness:
    i. the degree to which the military task is accomplished;
    ii. the degree to which the target recovers from the weapon effects within given constraints; and
    iii. the degree to which own troops, bystanders and the infrastructure or environment remain unaffected by the weapon effects.

SAS-035 recognized that modeling and simulation would be essential to support the methodology and surveyed various modeling tools in current use. The DRDC study that supported this survey concluded that most of the relevant models would require software modifications or development to convert them to NLW applications.[35] In addition, and

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32 Advisory Group for Aerospace Research and Development. Aerospace Applications Studies Cttee. Minimizing Collateral Damage During Peace Support Operations, volume I. Report no. AGARD AR-347-VOL-1, 1 Apr. 1999. Neuilly-sur-Seine, France: AGARD, 1999.

33 The Interim Report of Land Group 3 MOUT/NLW Team of Experts was published 3 May 2003.

34 NATO Document AC/259-D(2001)5(1) Road Map for the Development and Use of Non-Lethal Weapons Effective Engagement EE2(I), 1 February 2001. The other studies are SAS-040 and HFM-073.

35 Pierre Fournier, A Survey of Models for Non-Lethal Weapon Applications, Defence R&D Canada – Valcartier Technical Note TN 2002-121, November 2002, page 21.

perhaps more importantly, SAS-035 found that there was a scarcity of human (i.e. physiological and psychological) and material target response data with which to populate the models once the software was developed. The study recommended that nations be encouraged to collect these data and that a follow-on study be conducted to expand and further develop the assessment methodology. DRDC has expressed an interest in participating in the follow-on study.[36]

NATO RTO SAS-040 Non-Lethal Technologies for Future Peace Support Operations. The aim of this Long Term Scientific Study is to identify potential new NLW technologies that should be supported in the 2000 to 2010 time frame to ensure the NATO success in a full spectrum peace enforcement operation in 2020. It ended with a Multi-National Exercise in November 2003. DRDC was not a member of this study. [37]

NATO RTO SAS-041 Improving Land Armaments: Lessons from the Balkans. The aim of this study was to identify equipment shortfalls and suggest potential improvements for NATO land forces particularly related to interoperability and to synthesize lessons learned by the various nations involved in Balkans. It identified a number of capability gaps but singled out NLWs as one that could not be filled by adapting current systems. DRDC was not study member but the Army Lessons Learned Centre did participate.[38]

NATO RTO SCI-019 Tactical Implications of High Power Microwaves. This is a classified study in which DRDC participated that conducted experiments examining the technological issues inherent in its title.[39]

NATO RTO HFM-073 Human Effects of Non-Lethal Technologies. The aim of this study is to assess the physiological and psychological effects of non-lethal technologies. It will complete its work by the fall of 2003 and its major deliverables are likely to be a common NATO/PfP database of the human effects of non-lethal technologies. DRDC is not a member of this study.[40]

TTCP WPN Action Group 17 Non-Lethal Weapons. The consensus of this Action Group was that the physiological and especially the psychological effects of NLWs were not well understood and that this lack of knowledge hampered NLW R&D. It concluded its work in 2001 with a Joint WPN/HUM/JSA workshop on the psychological aspects of NLWs that showed some of the complexity of the issues involved.[41]

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[36]NATO Research and Technology Organization. Studies Analysis and Simulation Panel. Non-Lethal Weapons Effectiveness Assessment. Report no. RTO-TR-085, 1 Oct. 2004. CD-ROM. Neuilly-sur-Seine, France: NATO RTO, 2004.
[37]NATO Research and Technology Organization. Studies Analysis and Simulation Panel. Non-Lethal Weapons and Future Peace Enforcement Operations. Report no. RTO-TR-SAS-040, ISBN 92-837-1122-X, 1 Nov. 2004. Neuilly-sur-Seine, France: NATO RTO, 2004.
[38] NATO Research and Technology Organization. Studies Analysis and Simulation Panel. Improving Land Armaments: Lessons from the Balkans. Report no. RTO-TR-062, 1 Mar. 2003. CD-ROM. Neuilly-sur-Seine, France: NATO RTO, 2003.
[39] Wilbers, A.T.M. and E. Krogager. Tactical Implications of High Power Microwaves. Report no. RTO-TM-028, 1 Feb. 2003. Neuilly-sur-Seine, France: NATO Research and Technology Organization, 2003.
[40] HFM-073 Briefing to SAS-035 Meeting 15 May 2002.

TTCP HUM Action Group 22 Research Designs for the Assessment of NLW Human Effects. This Action Group stemmed from the recommendation of WPN Action Group 17. DRDC is a member of Action Group 22 and the first meeting was held in September 2003. Its aim is to determine a set of research designs to gather psychological and physiological data on target responses to counter-personnel NLWs. It recognizes that the lack of standardized experimentation methods is the most pressing deficiency in the collection of quality NLW human effects data. It specific objectives are to:

a. select the target responses to be investigated;
b. recommend appropriate test metrics for the response characteristics;
c. develop research options for selected technologies;
d. identify and apply acceptable ethical and legal boundaries for the developed options; and
e. recommend research protocols for the standardized assessment of NLW human effects.[42]

These ten international studies are a good measure of the level of NLW knowledge and R&D priorities of our allies. They suggest that since the mid-1990's the international R&D community has progressed from identifying technologies that may have non-lethal applications to identifying the main technological barriers facing NLW R&D.

13 Technological Barriers Facing NLW R&D

In general, it would appear that regardless of the naval, land or air force application, the major obstacles facing NLW R&D are the following:

a. Data on NLW Effects. The effects of the various non-lethal technologies must be understood as a first step in NLW R&D, otherwise it is difficult to identify the key areas that can be reasonably exploited to meet the user's requirements. Unfortunately, there is a scarcity of well-documented human and material target response data to the various NLW technologies. In particular, the human physiological and psychological effects of many NLW technologies are not well understood even by countries with large NLW programs. This situation is compounded by the lack of standardized research metrics and protocols to collect the data. This poses the question of how specific experiments are to be conducted with the requisite scientific rigour to collect the target response data and critically, how the correct non-lethal dosage can be calculated.

b. Modeling and Simulation Tools. Even when the effects of NLW technologies are known, modeling and simulation tools are needed to assess NLW operational effectiveness in realistic employment scenarios and analyse the cost/benefit ratio to the CF of the R&D investment. These tools have not been developed in part because the effects data needed to populate and exercise them have not been collected.

[41] The Task Outcome Report was distributed to TTCP under 1000-1 (DSTL 2) 1 March 2003. The author of this paper, LCol J.B. Dick, chaired this study.
[42] The HUM GROUP approved the formation of the Action Group at its Annual Meeting in July 2003.

c. Counter-Measures. The right to self-defence is never denied and counter-measures against non-lethal attacks may become an important force protection measure. The requirement may be particularly acute where the opposing force's NLW inventory is more extensive or advanced than our own. Some adversaries may not feel constrained by international law and develop chemical and biological NLWs that others may considered illegal or prohibited. For instance, there are readily available industrial and pharmaceutical chemicals that could be turned into chemical NLWs. This is particularly alarming if the physical incapacitation or behavioural change and subsequent treatment are unknown. The international studies described above did not consider non-lethal countermeasures against chemical or any other technologies in the NLW Taxonomy. It may be speculation to presume that our allies are actively working on countermeasures without positive knowledge of their R&D in this area. However, an understanding of possible countermeasures may be identified, as is often the case with lethal weapons, during the development NLW systems themselves. Unfortunately, nations are very reluctant to share this information and therefore, development of NLW countermeasures becomes a national responsibility.

14 Current DRDC NLW R&D Expertise

In the past DRDC has been involved in NLW R&D in several of its Research Centres, but work seems to have stopped in the mid to late 1970's.[43] By 1996 interest in NLWs began to revive. In that year a Research Note was produced giving a brief overview of NLWs[44] and a DRDC Technology Investment Strategy Workshop was held to discuss NLW capabilities and issues. It reviewed the key NLW issues of the day and recommended that for the time being, DRDC maintain a technology watch through NATO and TTCP.[45] This recommendation was followed and most DRDC NLW work since then has concentrated on the NATO and TTCP studies already mentioned. Actual scientific research was limited to a very small amount of classified work and the Non-Lethal Dazzler Miss Distance Estimation Model that was conducted in Thrust 2N in FY02/03.[46]

As productive as these activities have been, it cannot be said that DRDC has an active NLW R&D program at this time. But equally, it cannot be said that DRDC has no NLW expertise. There are some DRDC scientists involved in the lethal and human performance application of many of the scientific disciplines found in the NLW Taxonomy. The knowledge gained in blunt trauma, operational medicine, directed energy and the human response to chemical hazards are perhaps the most obvious examples. Scientists in all the Research Centres have

[43] A bibliography of unclassified Canadian NLW R&D reports was produced for WPN AG 17 in 1998 and is contained in WPN-DOC-AG-17-4-1998. Classified reports are available through DRDC/DRDKIM 2.

[44] Margolian, M. Non-Lethal Weapons: an Overview. Report no. ORD-DSA-RN-96-1, 1 Mar. 1996. Ottawa: Defence Research and Development Canada, Directorate of Strategic Analysis, 1996.

[45] Roy, R.L. Technology Investments Strategy Workshops Strategy Workshops, 9-10 October 1996 and 6-7 November 1996. Report no. DRDB-TISW-1996, 1 May 1997. Ottawa: DRDC, Directorate of Scientific Policy, 1997.

[46] This work was conducted under Project 12ns Indirect Fire System Study as WBE12ns13 during FY 02/03 and involves the neutralization of a gunner's ability to guide a missile. The report is classified because of the nature of the findings.

access to data sets that could be relevant to specific non-lethal effects and defensive or other countermeasures. Some scientific skills involved in some of these areas are undoubtedly more transferable than others, and time will be needed for anyone transferring their skills to become familiar with the technological issues and barriers facing NLW R&D.

The difficulty in starting NLW R&D is, of course, that scientists who possess the applicable NLW skills are fully engaged in the lethal or human performance projects. This is not surprising because that is where the priority has been up to now. The transfer of scientists' time and effort to NLW R&D is a question of competing priorities and limited resources. The evolution of the CF NLW requirements and the advance of non-lethal technologies over the past several years suggest that some priority and the requisite scientific resources should be allocated to NLW R&D.

15 Proposed Course of Action

The various Canadian NLW related activities indicate that the CF intends to use NLWs and either has in place or is staffing supporting concepts, doctrine, requirements, equipment acquisition and training to do so. The CCO manual and the DLR CCNLS project have changed the situation from academic or doctrinal discussion to actual NLW procurement and deployment. The question now is: should DRDC change its 1996 decision to maintain only a NLW technology watch and decide to start actual NLW R&D in response to user requirements? The lead user in this case would be the Land Force because it has the most developed capability requirements. There are clear indications where that R&D could be, namely the issues raised earlier by the international studies: scarcity of well-documented data on human and material target responses to NLW technologies; modeling and simulation tools; and counter-measures.

It is suggested that DRDC respond to this situation by either maintaining its current level of activity, reflected by Course of Action A, or by increasing the activity to address selected NLW issues, reflected by Course of Action B. These two Courses of Action are described in the paragraphs below.

Course of Action A.

a. Objective. Maintain a technology watch through NATO and TTCP participation in:
    i. TTCP HUM Action Group 22 Research Designs for the Assessment of NLW Human Effects.
    ii. Follow-on work to NATO SAS-035 Assessment of NLW Effectiveness.
    iii. Follow-on work to AC 225 Land Group 3 Military Operations in Urban Terrain/Non-Lethal Weapons Team of Experts.
b. Resources. Commitment of personnel time and travel funding.
c. Advantages.
    i. Only a slight increase in resources required beyond the current TD and FTE assignment due to the addition of the Land Group 3 Team of Experts.
    ii. DRDC stays connected to the international NLW community.

d. Disadvantages.
    i. The relevance of DRDC contribution will decline as NLW programs in other countries advance in content and sophistication.
    ii. DRDC will be unable to fully participate in information exchanges because it will have neither data nor intellectual property to contribute.
    iii. Allied nations may expect some funded R&D to take place as part of the as yet undefined Action Group 22 work plan. If DRDC does not support the R&D there is a risk that the interested countries will form a bilateral program that would exclude DRDC thereby restricting its insight into NLW developments.
    iv. The capability to advise the CF will be general in nature and therefore unlikely to address specific NLW issues or situations that may arise.

Course of Action B.

a. Objective.
    i. For a specific tactical level scenario, measure how the non-lethal use of blunt impact, directed energy and chemical agents can either control or disrupt a personnel or materiel target's: mobility, communication, physical function, ability to sense and interpret, group cohesion, identification and motivation.
    ii. Collect data that can be used in modeling and simulation to assess the operational effectiveness of blunt impact and directed energy applications in terms of the degree to which:
    iii. the tactical task is achieved;
    iv. the target recovers within the desired timeframe; and
    v. own troops, bystanders and the environment remain unaffected by non-lethal technology effects.
    vi. Identify possible counter-measures to the chemical agents and directed energies examined in the first objective.

b. Resources.
    i. TI/TA funding from Thrust 2N Munitions and Firepower for the blunt impact and chemical effects;
    ii. TDP funding, in accordance with TDP approval procedures, for the directed energy effects; and
    iii. Allocation of blunt trauma and laser and RF directed energy expertise.

c. Advantages.
    i. Supports informed future decisions by the CF on weapon procurement and tactical employment of blunt trauma and directed energy NLWs.
    ii. R&D of laser and RF directed energy NLWs would involve DRDC in technologies that hold considerable potential and pose dangerous threats.
    iii. Assists in determining force protection measures.

iv. Assists in the further development of a NLW assessment methodology.
v. The knowledge created will increase DRDC international relevance, possibly leading to NLW information exchanges with our allies.
vi. Capitalizes on existing DRDC blunt trauma and directed energy expertise.

d. Disadvantages.
    i. The capability to advise CF will be limited to the R&D areas selected.
    ii. R&D of blunt trauma NLWs would involve DRDC in technologies believed to be approaching the limits of its capabilities.
    iii. Funding and FTE resources will have to be reassigned from existing or planned projects.

The specific objectives, milestones, resources (both financial and human) and deliverables of the two Courses of Action have to be further defined. Some objectives, particularly in Course of Action B, are ambitious and may need adjustment to ensure the resulting project is achievable and affordable.

16 Conclusions

This paper has drawn the following conclusions:

a. The breath and depth of the NLW Technology Taxonomy requires that R&D be focussed in selected technologies if significant advances are to be made. Directed energy and chemical technologies (albeit with the latter's legal restrictions) seem to have greater growth potential than some other technology categories.

b. While a specific CF NLW policy has not been formulated, the CF has accepted the NATO policy and approved a CCO doctrine and training manual describing the intent to use NLWs in international and possibly domestic (i.e. when specifically ordered) operations.

c. Legal principles governing the use of force imply that the CF is expected to understand the probable effects of the NLWs it employs which will involve the assessment of NLW effects.

d. Ethical considerations will likely curtail the method of experimentation and collection of data needed to assess NLW human effects and operational effectiveness which increases the need for modelling.

e. Of the three environments, the Land Force has the most mature NLW concepts, doctrine and equipment requirements.

f. In addition to some Unforecasted Operational Requirements, the Land Force is staffing a project for a three stage procurement of NLWs for CCO in the near term while in the longer term, its concepts and doctrine suggest that NLWs could be used in a wider role across the spectrum of conflict.

g. International studies have indicated that the major technological obstacles facing NLW R&D are: the scarcity of well-documented data on human and material target responses to the various NLW technologies; the lack of modeling and simulation tools to assess the operational effectiveness of NLWs; and NLW counter-measures.

h. While DRDC has some experience in several of the NLW technology domains, its work has been largely directed to lethal and human performance applications and therefore its ability to advise the CF on NLW effects and effectiveness is very limited. The evolution of the CF NLW requirements over the past several years suggests that some priority and the requisite scientific resources should be allocated to NLWs.

17 Recommendations

In response to the emerging CF NLW requirements and advances in non-lethal technologies, it is recommended that DRDC change from the position it took in 1996 to maintain only a NLW technology watch to one of active R&D in selected non-lethal technologies. Specifically the R&D project should be based on Course of Action B described in paragraph 48. The R&D included in this work will allow DRDC to advise the CF with S&T knowledge on the effects, operational effectiveness and force protection measures of selected emerging NLW technologies.

18 Attachments

Annex A – Non-Lethal Weapon Technology Taxonomy
Annex B – NATO Non-Lethal Weapon Policy
Annex C – LF Urban Operations Working Group NLW Capability Requirements
Annex D – Project 0278 Close Combat Non-Lethal Systems, Unforecasted Operational Requirements Possible Equipment Acquisitions

1 Annex A - Taxonomy

Non-Lethal Weapon Technology Taxonomy

This Taxonomy categorizes possible NLW technology types and was developed by the NATO SAS-035[47] study which is based on the US Joint NLW Directorate Taxonomy. Specific NLW systems that use these and other technologies must comply with treaty and legal obligations.

Electro-Magnetic	Chemical	Acoustic	Mechanical Kinetic	Ancillary
Electrical Pulsed Current Direct Current **Radio Frequency** EMP Wide Band Ultra Wide Band **Microwave** High Power Microwave **Millimetre Wave** **Infrared** Lasers COIL* CO_2** HF/DF*** Solid State **Visible** Lasers Lights **Ultraviolet** Lasers **X-Rays**	**Obscurants** Rapid Hardening Agents Smokes **Reactants** Super-Corrosives Combustion Altered Viscosity Combustion Altered Fuel-Air Lubricant Contaminants Depolymerizers Embrittlers Emulsifiers **Malodorants** **Riot Control** **Anti-Traction** Lubricants Surfactants **Foams** **Thermobaric** **Nano-Particles**	**Audible** (20 Hz-20 KHz) **Audible/Optical** Flash Bangs **Ultrasound** (>20 KHz)	**Barriers** **Entanglements** Nets **Cloggers** **Blunt Impact** Projectiles Velocity Adjusting Water Stream **Vortex Ring Gun**	**Marker** Dyes Fluorescent Paints Taggers **Non-Lethal Casings** Frangible Combustible **Encapsulants** Micro-encapsulation

* COIL - Chemical Oxygen Iodine Laser
** CO_2 - Carbon Dioxide
*** HF/DF - Hydrogen Fluoride/Deuterium Fluoride

[47] NATO Research and Technology Organization. Studies Analysis and Simulation Panel. Non-Lethal Weapons Effectiveness Assessment. Report no. RTO-TR-085, 1 Oct. 2004. CD-ROM. Neuilly-sur-Seine, France: NATO RTO, 2004.

2 Annex B – NATO Policy

NATO Policy on Non-Lethal Weapons[48]

I. Purpose

1. The purpose of this document is to establish NATO Policy for Non-Lethal Weapons.
2. This policy applies to all NATO Non-Lethal Weapon research, development and acquisition programmes, employment of Non-Lethal Weapons, and related activities. It does not apply to information operations or any other military capability not designed specifically for the purpose of minimizing fatalities, permanent injury to personnel, and undesired damage to property and the environment, even though they may have these effects to some extent.

II. Definition

3. The following definition is applied as far as this policy is concerned:
Non-Lethal Weapons are weapons which are explicitly designed and developed to incapacitate or repel personnel, with a low probability of fatality or permanent injury, or to disable equipment, with minimal undesired damage or impact on the environment.

III. NATO policy

4. It is NATO policy that Non-Lethal Weapons, relevant concepts of operations, doctrine and operational requirements shall be designed to expand the range of options available to NATO Military Authorities. NLW are meant to complement the conventional weapons systems at NATO's disposal.

5. Non-Lethal Weapons should enhance the capability of NATO forces to achieve objectives such as (not necessarily in order of priority) to:

a. accomplish military missions and tasks in situations and conditions where the use of lethal force, although not prohibited, may not be necessary or desired;
b. discourage, delay, prevent or respond to hostile activities ;
c. limit or control escalation;
d. improve force protection;
e. repel or temporarily incapacitate personnel;
f. disable equipment or facilities;
g. help decrease the post-conflict costs of reconstruction.

6. The availability of Non-Lethal Weapons shall in no way limit a commander's or individual's inherent right and obligation to use all necessary means available and to take all appropriate action in self-defence.

[48] NATO Press Statement, 13 October 1999.

7. Neither the existence, the presence nor the potential effect of Non-Lethal Weapons shall constitute an obligation to use Non-Lethal Weapons, or impose a higher standard for, or additional restrictions on, the use of lethal force. In all cases NATO forces shall retain the option for immediate use of lethal weapons consistent with applicable national and international law and approved Rules of Engagement.

8. Non-Lethal Weapons shall not be required to have zero probability of causing fatalities or permanent injuries. However, while complete avoidance of these effects is not guaranteed or expected, Non-Lethal Weapons should significantly reduce such effects when compared with the employment of conventional lethal weapons under the same circumstances.

9. Non-Lethal Weapons may be used in conjunction with lethal weapon systems to enhance the latter's effectiveness and efficiency across the full spectrum of military operations.

10. NATO planners shall ensure that the potential contribution of Non-Lethal Weapons is taken fully into account in the development of their plans.

11. Non-Lethal Weapons shall conform to the definition contained in Section II above and have, as a minimum, the following characteristics:

a. they must achieve an appropriate balance between the competing goals of having a low probability of fatality or permanent injury, with minimal undesired damage, and a high probability of having the desired effects;
b. they must not be easily defeated or degraded by hostile countermeasures once known or, if they could be so defeated, the benefits of a single opportunity to use such a weapon in a given context would, nevertheless, be so great as to outweigh that disadvantage or any risk of consequent escalation.

12. The research and development, procurement and employment of Non-Lethal Weapons shall always remain consistent with applicable treaties, conventions and international law, particularly the Law of Armed Conflict as well as national law and approved Rules of Engagement.

IV. Additional Policy Guidance

13. Any future request for additional policy guidance shall be referred to the North Atlantic Council.

3 Annex C – Capability Requirements

Land Force Urban Operations Working Group
Non-Lethal Weapon Capability Requirements

1. The Final Report of the Land Force Urban Operations Working Group produced a matrix of 52 operational level capability requirements for urban operations and identified potential solutions for each capability across the PLOTED mnemonic.[49] The Equipment portion of PLOTED was divided into solutions currently available and those requiring R&D. The Equipment – R&D column contained the following NLW solutions. The repetition of some NLW solutions indicates the multiple uses some capabilities.

   Primary NLW Capability

2. Apply Non-Lethal Effect.

   a. Non-lethal techniques to control crowds under certain prescribed conditions.

   b. Anti-personnel NLWs such as calmatives, malodorants, acoustics, lights and holograms.

   c. Non-lethal mechanical (i.e. caltrops, airbag mines, ropes, spikes, entanglements), chemical (i.e. rigid, slippery, aqueous foams) and electro-magnetic (i.e. lasers, heat guns, high powered microwaves) and barriers.

   d. Tagging or multi-spectral marking.

   e. Anti-material NLWs to stop vehicles, aircraft and vessels.

Secondary NLW Capabilities

3. The Ability to Assess Effects.

   a. Validated predictive model of the weapon effects in the urban terrain that includes the assessment of combined effects of different weapon strikes against the same target.

   b. Post strike analysis in real time through indirect fire data acquisition rounds and remote sensors.

4. Identify the Location, Status, Numbers, and Intent of the Local Population.

   a. Models that can predict the actions of the targeted population.

   b. Tagging or multi-spectral markers.

[49] Land Force Urban Operations Working Group Final Report, 29 May 2002.

5. Distinguish Between Blue/Red/Non-Combatants.

    a. Identification Friend-Foe-Neutral System.

6. Control Population Movement and Non-Combatant Manœuvre.

    a. Non-lethal Techniques to control crowds under certain prescribed conditions.

    b. Non-lethal Weapons such as calmatives, malordurants, acoustics, dazzle lights, holograms etc.

    c. Non-lethal mechanical (i.e. caltrops, airbag mines, ropes, spikes, entanglements), chemical (i.e. rigid, slippery, aqueous foams) and electro-magnetic (i.e. lasers, heat guns, high powered microwaves) and barriers.

    d. Tagging or multi-spectral marking.

7. Conduct Counter-Mobility Operations.

    a. Lethal and Non-lethal barriers.

    b. Non-lethal point and area denial weapons.

    c. Anti-material NLWs.

    d. Anti-infrastructure NLWs.

8. Create Urban Field Fortifications.

    a. Lethal and non-lethal barriers.

9. Provide Individual Protection.

    a. Lethal and Non-lethal barrier removal equipment.

    b. Identification Friend-Foe-Neutral.

4 Annex D – Operational Requirements

Project 0278 Close Combat Non-Lethal Systems
Unforecasted Operational Requirements
Possible Equipment Acquisitions

1. The Close Combat Non-Lethal Systems project has adopted a three-stage approach to acquire the following equipment:[50]

a. First Level – Basic Force Protection. This funded procurement consists of these 16 items of equipment (those marked with a * have already been procured) to be worn or used by individual soldiers:

   i. face shield/helmet visor, non-ballistic;
   ii. body shield, large and small, non-ballistic*;
   iii. riot shin guards, non-ballistic;
   iv. nape protector;
   v. forearm protector or glove*;
   vi. protective (fragmentation) vest* - not actually part of the CCNLS;
   vii. baton (riot stick) wooden*;
   viii. fire retardant CADPAT coveralls;
   ix. bullhorn portable*;
   x. high intensity light, individual*;
   xi. high intensity light, large*;
   xii. flex cuffs*;
   xiii. OC canister, individual*;
   xiv. caltrops or other anti-material barricade;
   xv. riot training suit with accessories;
   xvi. riot training bag;
   xvii. Standoff weapon and ammunition.

b. Second Level – Enhanced Standoff. This requirement is still being evaluated but examples of possible equipment are:

   i. OC canister, large capacity;
   ii. riot control agent, mid size dispenser; and
   iii. water cannon.

c. Third Level – Combined Arms Crowd Confrontation Operations: This stage of the project is yet to be defined but will addresses the requirement for barriers and special purpose CCO vehicles such as an engineer tractor, a modified LAV and a "snatch" vehicle.

[50] DLR 5-5 Briefing to Land Force Combat Development Board 21 March 2002.

2. Some of the non-lethal ammunition being considered for the first level are:

a. 40mm Sponge Grenade Projectile. This projectile was developed for the M203 grenade launcher made out of spongy material and was type classified by the US in FY 99. It is designed to incapacitate an individual at 15 to 30 metres.[51]

b. 12-Gauge Fin Stabilized Projectile. This rubber, fin-stabilized bomblet-shaped projectile is fired from a 12-gauge shotgun. It has an engagement range of 10 to 20 metres and is most effective against individually selected targets.

c. Projectile, Drag Stabilized Sock Round. This round consists of a fabric sack filled with lead shot (usually No. 9) weighing from 40 to 150 grams that is fired from a 12-gauge shotgun. The sacks conform to the shape of the target on impact, producing less damage than a solid hard projectile. These projectiles are designed for direct impact on the target; therefore accuracy is important to ensure an effective hit. The level of energy delivered ranges from 40 to 100 foot-pounds, depending on the distance the projectile travels.[52]

d. Flash Bang Grenade. These grenades combine audible and optical technologies to create loud sounds with accompanying dazzling light to cause a distraction.[53]

3. In addition to the above, the following types of equipment might be procured through an unforecasted operational requirement:[54]

a. male athletic supporter;
b. female groin guard;
c. public address system;
d. gloves;
e. leg protectors;
f. face shield; and
g. body shield.

[51] CFLO ARDEC letter, 2511-7-8 (ARDEC), 25 September 2001.
[52] NATO Research and Technology Organization. Studies Analysis and Simulation Panel. Non-Lethal Weapons Effectiveness Assessment. Report no. RTO-TR-085, 1 Oct. 2004. CD-ROM. Neuilly-sur-Seine, France: NATO RTO, 2004.
[53] Ibid.
[54] DLR 5-5 E-mail dated 20 May 2003.

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Annex G. Non-Lethal Effects Evaluation Methodology

By

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July 2004

Foreward

Over the last 10 years, the Canadian military has been involved in an increasing number of UN and NATO peace support operations where the priority is to minimize casualties, reduce damage to equipment and infrastructure, and contain conflict. The current training, doctrine and equipment are built around lethal weapons, which means that the troops conducting peace support operations found themselves in situations where their only options were to posture with lethal weapons or use them. This is obviously inadequate. Hence the introduction of Non Lethal Weapons (NLW) that are not meant to replace lethal weapons but rather to provide the military commander with a broader range of options than those currently available.

The Department of National Defence appointed two representatives to the NATO Studies, Analysis and Simulation (SAS) study team. The objective was to obtain the basic knowledge on NLW necessary to launch a NLW R&D program in DRDC.

This technical note is structured in two main parts. Part one is a reproduction of chapter 3 of SAS-035 Final Report that was written by Dr. Marcus Naraidoo. The need to be able to assess the effect of NLW on potential targets, especially humans, cannot be overstated. Contrary to lethal weapons, it is desired that effects of NLW, especially their effects on humans, are limited in time and fully reversible. This poses a particular challenge to the R&D community who designs NLW, to the requirements community who has to select NLW based on their stated performance, operational effectiveness and cost, and finally to the operational commander who has the final decision in using lethal or non-lethal weapons and who will have to live with the consequences of his/her decision.

The current state of knowledge on human effects of NLW is limited. The NLW effects evaluation framework developed by SAS-035 is one of the many steps in developing our understanding of these effects.

The second part is a summary of a survey of models that could support NLW studies. Most of the models identified in this survey are available in Canada. Empirical studies and models are required to understand the effects of NLW on their targets. The survey of models conducted at the request of SAS-035 identified a number of such models and empirical studies. It is to be noted that the models identified in the survey will require a certain amount of development before they could be used for NLW studies.

Pierre Fournier

1 Introduction

Before Non-Lethal Weapons can realistically be accepted by military planners and commanders for a wider variety of operations, it is necessary to establish how useful they may, or may not, be. Until now, the usefulness of NLWs has been determined on an *ad hoc* basis. However, a key objective of SAS-035 has been to establish a mechanism that can robustly and repeatably determine the Measures of Effectiveness of NLWs with less ambiguity and subjectivity.

The methodology is a combination of ordered processes and mathematical operations, working on sets of data and constraints with the purpose of generating a number of objective outcomes. Implicitly, the methodology defines a software or system architecture. This architecture could be encoded to produce a tool or a check-list, and these could be used to generate quantifiable Measures of Effectiveness (MoEs). For the purposes of this study, SAS-035 divided MoEs into two types: Measures of System Effectiveness (MoSEs) and Measures of Operational Effectiveness (MoOEs), both of which are explained in this chapter.

2 Defining the Problem

Figure 1 depicts the various sets of data and constraints and how they need to interlink in order to determine MoEs for NLWs (the scope of SAS-035's work – developing means for calculating system effectiveness – is within the shaded box). In fact, during the course of the study it became apparent that this methodology is more broadly applicable and could also be used for conventional weapons. The following set of definitions help to explain the figure.

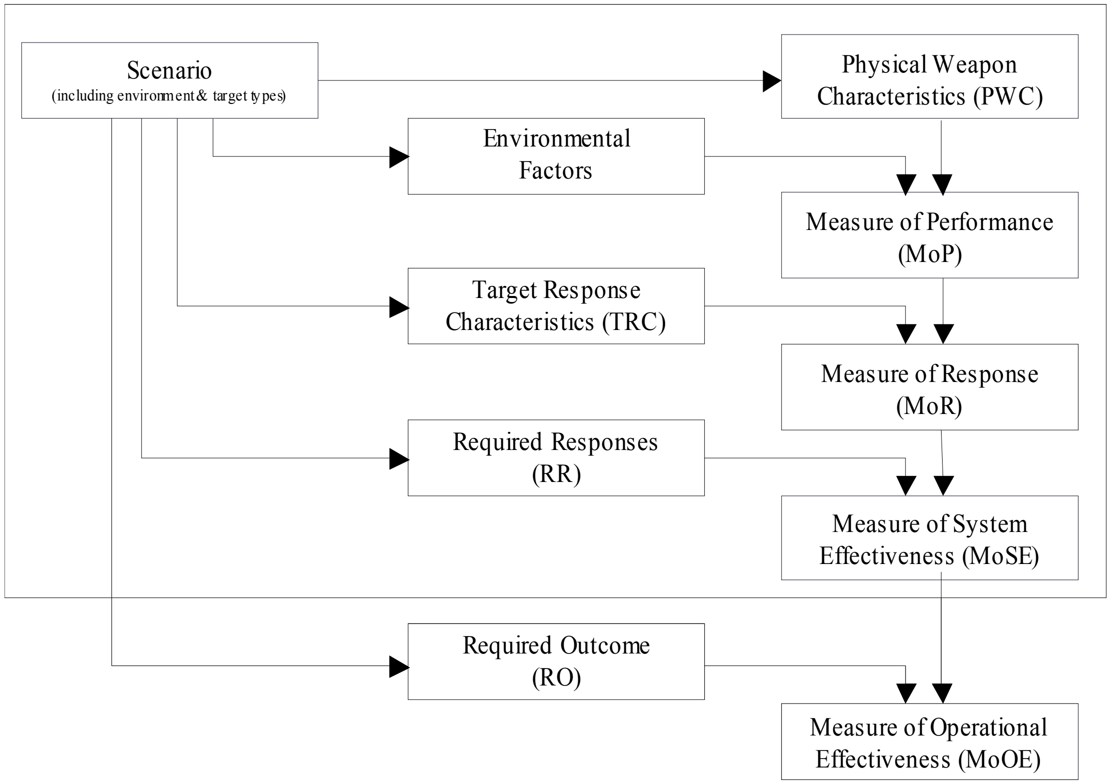


Figure 1 : *Defining the problem.*

2.1 Physical Weapon Characteristics

Physical Weapon Characteristics (PWC) are the intrinsic qualities of a weapon under consideration and include the dimensional design values associated with a weapon, such as; weight, calibre, size, range in ideal conditions, power requirement, shelf life, etc. Generally any weapon or technology will have a set of PWCs.

2.2 Measure of Performance

A Measure of Performance (MoP), as illustrated in Figure 2, is the combination of the PWCs with environmental factors such as wind and weather, topography, buildings and so on. Measures of Performance can be thought of as the environmentally modified PWCs. Some typical MoPs may be:

- concentration of an obscurant
- terminal momentum of a baton round
- optical intensity of a flash-bang
- sound pressure level of a grenade

- adhesiveness of a water soluble foam
- area coverage of a net
- field strength of a directed energy weapon.

Each of these MoPs may be determined by mathematically combining the PWCs with the environmental factors from the operational scenario or mission. There is not necessarily a one-to-one mapping of PWCs to MoPs.

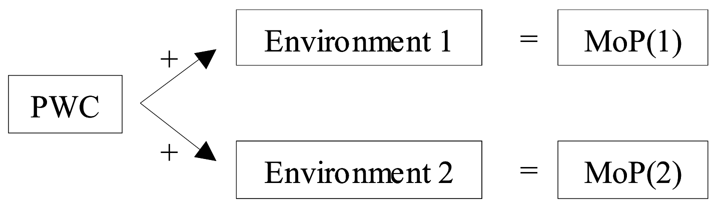


***Figure 2 :** The combination of physical weapon characteristics and environmental conditions produces different Measures of Performance.*

2.3 Target Response Characteristics

Different targets will react differently to each type of weapon. For example, consider the impact of a baton round. A young man without protective clothing, a young man wearing protective gear, and a tank will react very differently to being hit by a baton round. Target Response Characteristics (TRCs) describe how a target will respond to a particular weapon.

Target responses for lethal and non-lethal weapons are a function of time. They may be a step function, with a permanent, unchanging response (e.g., a lethal weapon successfully killing a target), or the target may fully recover within a time relevant to the scenario, a desired property of NLWs. This time varying nature of target response is highly important in assessing effectiveness, and it is captured by this methodology. Additionally, this methodology enables the use of counter-measures (e.g., sun glasses, ear defenders, tyre shields etc) to be included within the formulation of the TRCs.

2.4 Measure of Response

A Measure of Response (MoR) is the combination of the MoP and the TRC, as shown in Figure 3.

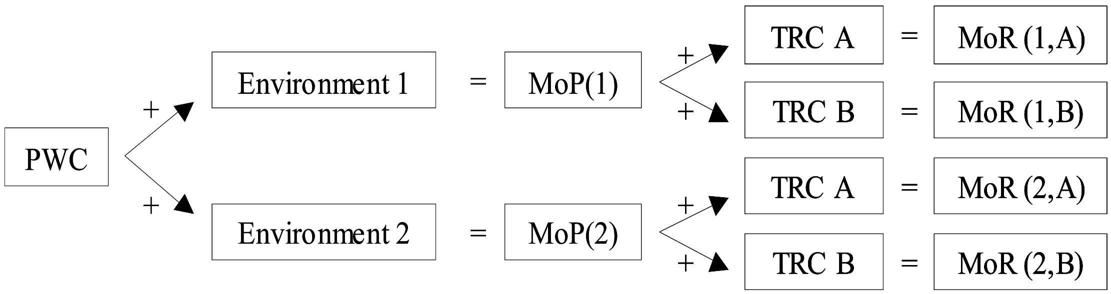


***Figure 3 :** The combination of MoP and of Target Response Characteristics produces different Measures of Response.*

SAS-035 identified seven generic responses that can be used to describe how targets behave as the result of the application of a weapon or technology employed against them. These Basis Responses are the smallest set of descriptors that can individually or in combination express the desired target responses associated with all of the anti-personnel and anti-materiel tasks (and constraints). These Basis Responses describe the Required Responses and Measures of Response in a simple and common manner such that they can be mathematically compared in order to compute the Measures of Effectiveness. They are a means of reducing complex information to a minimum ordered set of actions to allow the Measures of System Effectiveness to be mathematically calculated. The following seven Basis Responses have been identified.

Mobility: The ability to disrupt or control the speed (i.e. by starting, increasing, decreasing or stopping), and/or the direction of movement (i.e. by containing or changing) of targeted individuals, groups of individuals, vehicles, vessels or aircraft. Mobility includes altering the altitude of aircraft and depth of submarines.

Communication: The ability to disrupt or control by either restricting or enhancing verbal communication via voice or gestures between targeted individuals or groups of individuals.

Physical Function: The ability to disrupt or control by either restricting or enhancing the:

capacity of targeted individuals or groups of individuals to accomplish their task (i.e. by restricting the movement and/or reducing the strength of limbs, hands, head and neck); and

physical state of equipment (or one or more of its components) such that it is inoperable or functions at reduced efficiency.

Sense and Interpret: The ability to disrupt or control by either restricting or enhancing the:

vision, smell, hearing and cognition (e.g. the capacity to reason, perceive and remember) of targeted individuals or groups of individuals; and

the operation of artificial intelligence systems in autonomous intelligent vehicles, vessels or aircraft.

Group Cohesion: The ability to disrupt or control a group of individuals or co-operatively operating vehicles, vessels or aircraft by either restricting or enhancing their organisation, co-operation and density.

Motivation: The ability to disrupt or control the targeted individual or group of individuals by either restricting or enhancing their will to act in certain ways in order to achieve a goal.

Identification: The ability to differentiate between various individuals, groups of individuals, vehicles, vessels or aircraft through an identifiable designation.

Generally there will be more than seven elements to the set of MoPs. However, the TRCs take the form of a weighted series of factors (see Annex D in [1]), which combine with the MoPs to generate seven, and only seven, MoRs for each and every weapon/environment/target combination.

3 Required Response

A Required Response (RR) is the response required of a chosen target for scenario success. It links a particular target engagement with a weapon or technology at a particular time in the scenario or mission. The required responses are specified in terms of values for each of the seven basis responses, schematically illustrated as a function of time in Figure 4. These values are:

- **onset time**: this is the period between the deployment of the weapon system and the point when the magnitude of the desired effect attains some particular threshold. Ideally, the onset time is equal to zero.

- desired **magnitude** of the target effect: this is the qualitative or quantitative response that the target should display once the weapon system has taken full effect (e.g., to stop an individual from moving, or to make a vehicle move directly away etc)

- desired **duration** of the target effect: this is the period after the onset time that the target should exhibit a particular response greater than some particular threshold

- desired target **recovery**: this is the period when the target response falls below a particular threshold and a full recovery of unimpaired functionality is desired in an operationally meaningful context. Ideally, full recovery occurs immediately at the end of the desired duration.

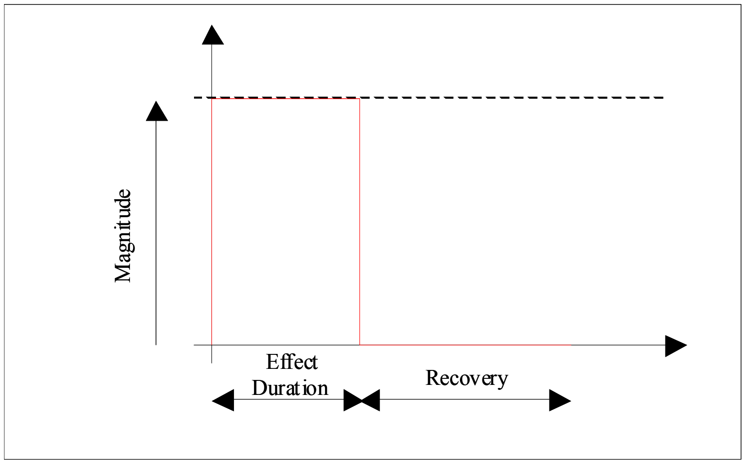


Figure 4 : *Specifying Required Responses.*

Although the curve depicted in Figure 4 is a back-to-back step function, any shape of response curve is acceptable as the methodology is generally applicable.

4 Measure of System Effectiveness

A Measure of System Effectiveness (MoSE) is a functional comparison between the Required Response (RR) and the Measure of Response (MoR) for one single weapon system used once, for a task in the scenario or mission of interest.

A single weapon used in different environments, against different targets, or for different tasks will result in different Measures of System Effectiveness, as illustrated in Figure 5.. The MoSE itself may be calculated in a number of ways, and this is covered more fully in Section 11.7.

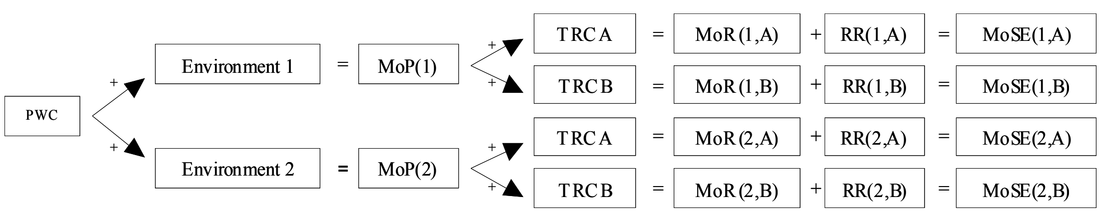


Figure 5 : *Measures of System Effectiveness.*

4.1 Required Outcome

The Required Outcome (RO) considers the entire operational context of a mission or scenario. It reflects the accomplishment of multiple tasks and the satisfaction of associated constraints over time.

4.2 Measure of Operational Effectiveness

The Measure of Operational Effectiveness (MoOE) is a comparison between the Required Outcome and a number of MoSEs. It reflects the effectiveness of one or more lethal or non-lethal weapons used concurrently, sequentially, or repeatedly to achieve the Required Outcome.

The scope of the work undertaken by SAS-035 covers all of the above except Required Outcomes and Measures of Operational Effectiveness. The area within the shaded region of Figure 1 illustrates the scope of the work, and the methodology, developed during this study. Further work is necessary to extend this to Measures of Operational Effectiveness.

5 The Basis Responses

The first of the two main findings of the SAS-035 study is the following. All of the task requirements (with associated constraints) are a function of time and can be expressed using seven simple, generic factors. These factors are called the ***Basis Responses***, as shown in Figure 6.

$$\textit{Requirement (t)} = \begin{pmatrix} \textit{Mobility (t)} \\ \textit{Communication (t)} \\ \textit{Physical Function (t)} \\ \textit{Sense (t)} \\ \textit{Cohesion (t)} \\ \textit{Motivation (t)} \\ \textit{Identification (t)} \end{pmatrix}$$

Figure 6 : *Requirement is a function of time and is expressed as a function of the Basis Responses.*

Care was taken to ensure that these Basis Responses are as applicable generally to material (such as vehicles) as they are to personnel.

The difficulty that SAS-035 encountered in developing the assessment methodology was that the parameters often used to describe mission success (i.e. the Required Response) did not accurately describe the target effects necessary to produce that response. Since the seven Basis Responses, or a combination of them, describe all the required target responses for a wide range of tactical missions and target effects against which mission success can be measured (i.e. the MoE) they, therefore, provide a mechanism for both calculating the MoRs and for specifying the RRs. In both cases they provide a means of convergence between two different ways of thinking. The Basis Responses form the smallest common set of variables that can be simply combined to reduce complex information into an ordered set of measurable quantities.

In other words, the RRs are the responses that a military commander wishes a target to display. They are obtained by considering the mission or scenario. They can be obtained by expert judgement, appropriate models or some other means.

The MoRs are the responses that a weapon, chosen for deployment in that mission or scenario, would have on the targets under consideration, once the environmental and target characteristics are taken in to account.

By requiring that the RRs and the MoRs are described through the use of the same seven Basis Responses it becomes possible to make a comparison, at a mathematical level, which provides the MoSE. Without achieving some convergence of terminology between the RRs and the MoRs such a quantitative comparison would otherwise be impossible.

A key benefit is that these Basis Responses can also be used to characterise conventional weapon performance. This is a valuable characteristic as it will enable comparisons between conventional (lethal) weapons and non-lethal weapons to be made on common missions and scenarios.

The importance of these Basis Responses will become apparent in the worked example of Annex D in [1].

Although seven Basis Responses have been identified so far, and in the cases considered they have been the smallest number that can adequately describe all of the various tasks, it is important to recognise that some additional Basis Responses may emerge. For example, if the responses of a target were to extend beyond the ones captured by these Basis Responses to new ones (perhaps of a psychological nature), then one or more new Basis Responses would have to be identified to describe (either qualitatively or quantitatively) these effects.

However, it is important to recognise that the framework identified as part of this NATO study is robust to the addition (or deletion) of Basis Responses. As long as the Target Response Characteristics (TRCs, see Section 11.7) can be extended to embrace these changes it will be equally possible to generate revised MoRs. The comparison process where these MoRs are combined with Required Responses (RRs) is equally possible as long as the RRs also include these changes.

In practice this would require the RR score cards (see Section 11.7 and in particular Table 1) to be extended to cover these changes, and for any software and data files to also be suitably modified. Although these may require some changes to process and procedure and some software maintenance, the fundamental framework identified in this NATO study remains unaltered.

Furthermore, the Basis Responses can either be absolute values or relative values. For instance, it may be that loud and persistent rock music has twice the demoralising effect on an old lady as it does on a young man. In this example the magnitude of the Basis Response for motivation would be twice that for the old lady as the young man, and this is a relative value not an absolute one.

In summary, this framework is robust to changes in the type, form and detail of the Basis Responses. Where this methodology stops, and perhaps one area where follow-on work should proceed, is in the aggregation of effects as discussed in Section 11.7. The current SAS-035 activity only considers the effect of one weapon used once but it is interesting to consider: one or more weapons used sequentially, concurrently, and/or repeatedly. The analysis of such deployments is beyond the scope of SAS-035 and is more of a Measure of Operational Effectiveness issue than a Measure of Systems Effectiveness one.

6 Target Response Characteristics

The second of the two main findings of the SAS-035 study is the following. The response of any target may be expressed in terms of the same Basis Responses as the task requirement. The response is a function of the target's characteristics, a weapon's MoPs and is also time dependent, especially in terms of target recovery (see Figure 7).

$$\mathit{Response}\ (t) = \begin{pmatrix} \mathit{Mobility}\ (t) \\ \mathit{Communication}\ (t) \\ \mathit{Physical\ Function}\ (t) \\ \mathit{Sense}\ (t) \\ \mathit{Cohesion}\ (t) \\ \mathit{Motivation}\ (t) \\ \mathit{Identification}\ (t) \end{pmatrix}$$

Figure 7 : *Target Response is a function of time and is also a function of the Basis Responses.*

This is a very important observation, and is as crucial to the implementation of this methodology as the seven Basis Responses. The Target Response Characteristics are the transfer functions, which will convert the (many) MoPs into the (seven) MoRs.

Consider the following; target A is a healthy young man and target B is an infirm child. If either is engaged identically with a non-lethal kinetic energy projectile, for example, then the MoPs of the weapon will be the same. However, the way targets A and B respond to the projectile may be different in each case. The calculation of these MoRs will use the same MoP data in both cases, but will generate different MoRs simply because the TRCs are different. So it may be the case that the mobility of target B is influenced to a greater degree and for longer. It may be the case that target B is more disoriented than target A once engaged. In fact, it may be that target A becomes more motivated (enraged) rather than less motivated!

The ability to describe both positive and negative responses is captured completely within this methodology and is done through the TRCs. Once again, this will be discussed more fully in Section 11.7.

The crucial discovery of the SAS-035 study is the importance of Target Response Characteristics. The further development and population of a database of TRCs will be an important recommendation for any NATO follow on study.

7 The Importance of Time: Effects' Duration and Target Recovery

An important distinction between NLWs and conventional weapons is that the effect of NLWs on a target, whether human or materiel, is intended to be reversible [3].

This is illustrated in Figure 8. Consider a Required Response indicated by graph R. A particular NLW may achieve the MoR indicated by curve N. We see that in this case the NLW continues to have an effect on the target beyond the required duration and drops to zero, indicating that the effect was fully reversible, by some time T_e, which here is greater than the desired recovery time. A lethal weapon, by comparison, could be depicted by curve L. This weapon achieves, and in fact, exceeds the magnitude of the required response (as the NLW does) and does so for as long as the required duration (unlike the NLW) but there is no recovery whatsoever by the desired recovery time.

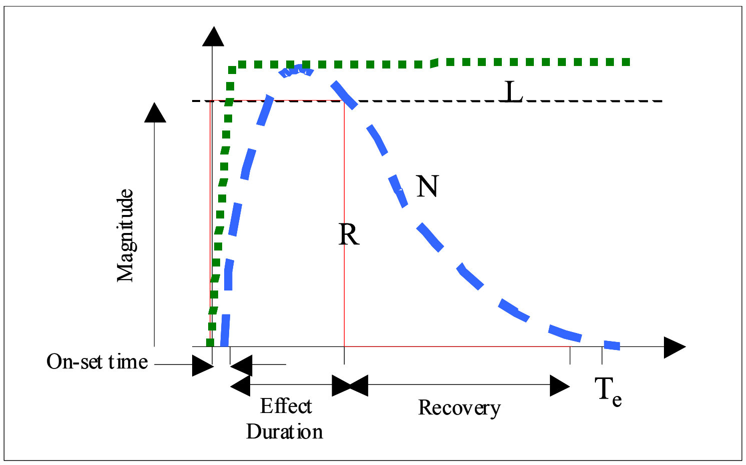


Figure 8 : *Time – Effects' Duration and Target Recovery.*

By considering the three factors; magnitude, duration and recovery time it is possible to distinguish between:

- various NLWs
- NLWs and conventional weapons and
- different mission or scenario requirements (RRs) in each case.

It is via these factors that mission constraints and issues surrounding collateral damage can be considered quantitatively. To illustrate this we now introduce three variables which, when considered collectively, can be thought of as components of the MoSE.

7.1 The Task Objective, P_1

The Task Objective, denoted $P_{1,}$ is the successful achievement of the military task. A particular task may require a target response of a certain form, and for this to last for a specified duration.

The value of P_1 could be calculated as the ratio of the area $A_{1,1}$ to the region enclosed by rectangle ***abcd*** shown in Figure 9. Note, that for the purposes of this methodology, when a weapon response exceeds the mission's required responses, the over-area does not contribute to the sum. More about the mathematics of this process can be found in Annex D of [1].

Such a ratio has the property that $0 \leq P_1 \leq +1$ (in fact the limit is strictly $-1 \leq P_1 \leq +1$). Thus, when a required response is precisely met by the weapon's measure of response for the target under consideration in that mission, the value of P_1 is unity ($P_1 = +1$).

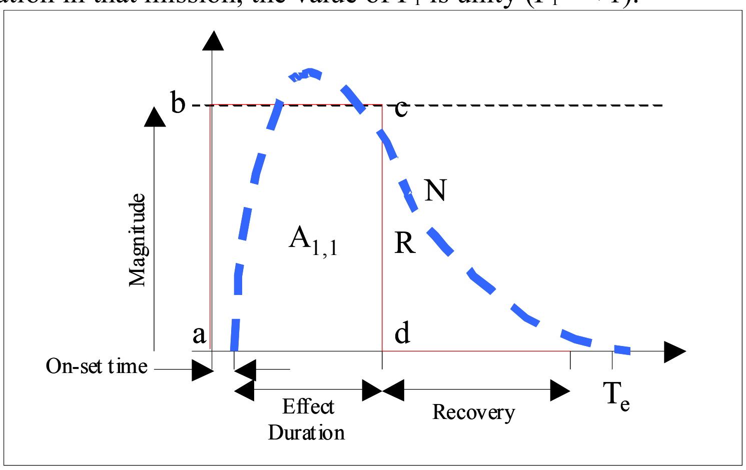


Figure 9 : Calculating the value of Task Objective, $P_{1.}$

7.2 The Task Objective, P_2

A particular mission may require the partial or complete recovery of the intended targets after a certain time. This could be considered the Target Constraint, denoted P_2.
Similarly, in this methodology P_2 can be considered as the ratio of the area between two curves as illustrated by the shaded region $A_{2,1}$ and the region bounded by the rectangle ***cdpq*** in Figure 10.

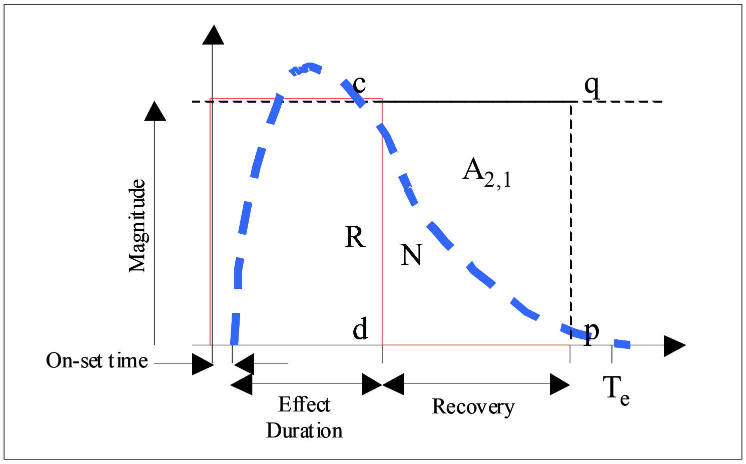


***Figure 10 :** Calculating the value of the Target Constraint.*

Once again, the ratio has the property that $0 \leq P_2 \leq +1$ (in fact the limit is strictly $-1 \leq P_2 \leq +1$). Thus, when a target completely recovers during the recovery time the value of P_2 is unity ($P_2 = +1$).

7.3 The Collateral Constraint, P_3

A particular mission may wish to limit the impact of a weapon against non-intended targets (e.g., bystanders, own forces, infrastructure, and so on). This is called the Collateral Constraint, which is denoted P_3.

When the use of a weapon inadvertently affects those other than the intended target, it is likely that the MoR curve differs from that of the same weapon directed against the intended targets. Furthermore, it is likely that the acceptable (vice desired) responses in terms of the magnitude, duration and recovery times are different too. This results in N' and R' response curves for the NLW and for the Required Response which are different from those which are appropriate for the same weapon but when used against the intended targets (N and R in the figures above).

Figure 11 illustrates the means of calculating the P_3 value. This is the ratio of the shaded area $A_{3,1}$ to the area of the region bounded and enclosed by the line ***abcd***. In practice the magnitude of the required response against unintentional targets may be specified as zero for a duration of zero[1].

[1] Note: In reality there will be some non-zero effect on unintentional targets, and this effect will have a finite, non-zero, duration. This is discussed more fully in Annex D of [1].

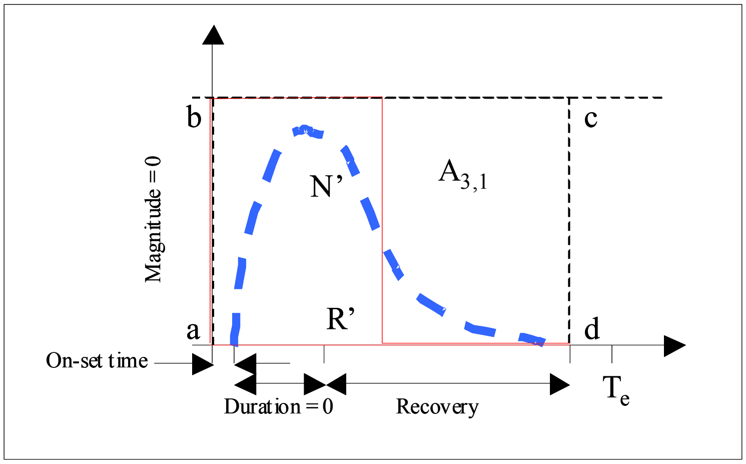


***Figure 11 :** Calculating the value of the Collateral Constraint.*

Ideally, the response curve of the NLW when affecting those other than the intended targets, depicted as N in Figure 11, has zero magnitude everywhere and, in this case, the ratio leads to a value of $P_3 = 1$. As in the previous cases, this definition of the Collateral Constraint yields $0 \leq P_3 \leq +1$ (in fact the limit is strictly $-1 \leq P_3 \leq +1$).

The three P-factor vectors, as calculated above, constitute Measure of System Effectiveness (MoSE) vectors. They provide a measure of how well a weapon addresses the task objective (P_1), target constraints (P_2) and collateral constraints (P_3). They do so by functionally comparing Required Responses (the curves denoted R in the above Figures) with the actual Measures of Response of the targets to the weapons under the conditions of use (the curves denoted N in the above Figures).

8 Desirable and undesirable responses

It has to be recognised that some actions, such as the deployment of a particular NLW against certain targets, may result in either desirable or undesirable responses. This methodology is capable of addressing both within the same framework and is one of the strengths of this approach.

Consider the following example, depicted schematically in Figure 12. The objective of this phase of a mission is to ensure that the targets at T_1 and T_2 do not approach a defender, D, more closely. A non-lethal weapon is selected and deployed and it hits the ground at a point H. If the NLW is a gas, for instance, then the result could be that the targets at T_1 move further from the perimeter, whilst the targets at T_2 move closer to it[2]. In this case the same non-lethal weapon elicits two different responses, the first is a desirable response on the targets T_1 whereas the second is an undesirable response on targets T_2.

[2] Note, it is unlikely that a military commander would wish to perform such an action, but it could be that the wind conditions carry such a weapon further than intended, resulting in it dropping between the targets rather than in front of them.

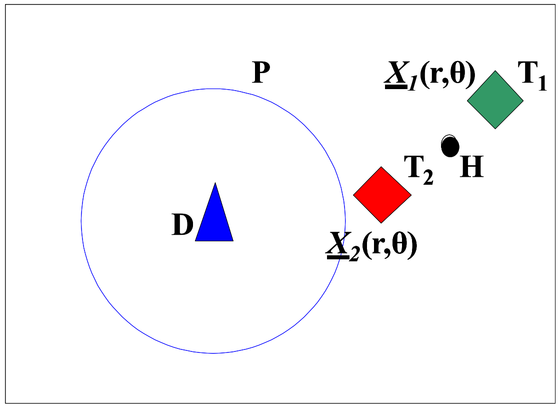


Figure 12 : Desirable and undesirable responses.

This methodology can adequately capture both of these responses. Consider the Mobility Basis Response.

Figure 13 illustrates both the desirable response of targets T_1 (by the blue dashed curve enclosing area $A_{1,1}$ within the region ***abcd***) and the undesirable response of targets T_2 (by the green dash-dot curve enclosing area $A_{2,2}$ within region ***aefd*** and area $A_{2,1}$ within region ***abcd***).

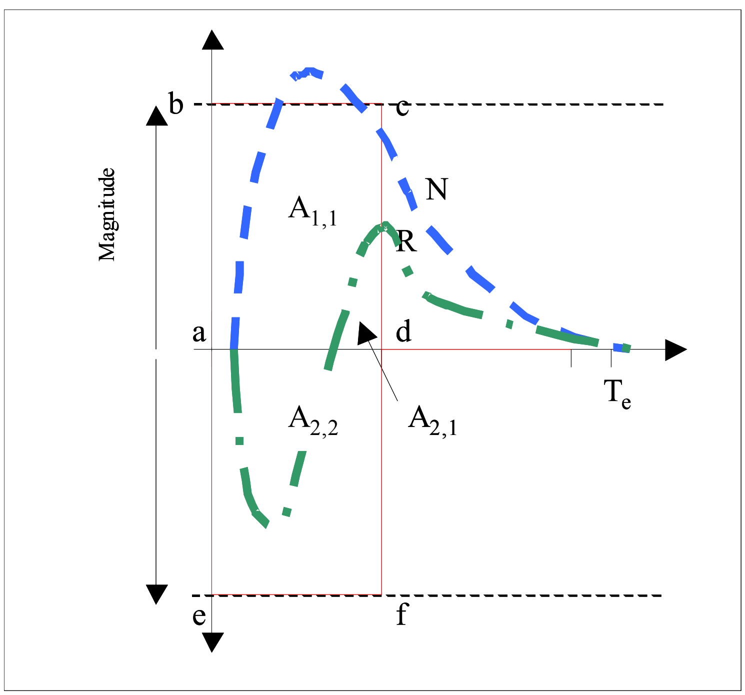


Figure 13 : Calculating undesirable responses.

By analogy with the Task Objective, P_1, is calculated as follows.

For the targets T_1 : $P_{1,T1} = A_{1,1}/\text{Area}(\boldsymbol{abcd})$

For the targets T_2 : $P_{1,T2} = A_{2,1}/\text{Area}(\boldsymbol{abcd}) - A_{2,2}/\text{Area}(\boldsymbol{aefd})$

As a result, it is clear that if the targets T_2 behave in a totally undesirable fashion then area $A_{2,1}$ would equal region ***aefd*** and the value of P_1 would be –1. In this case the value of area $A_{2,2}$ would be zero and these targets would not display any desired responses during the desired effect duration.

The Target Constraint, P_2, and the Collateral Constraint, P_3, can be similarly extended to cover instances when the target responses are undesirable[3].

It should be noted that the case depicted in Figure 13 could represent the motivation Basis Response. The green dashed curve represents the motivation of a young man when fired on by, for instance a baton round. Initially his reaction is to be more highly motivated than he was before, hence the drop in the curve below the zero line. As time progresses, his motivation lessens and he becomes less motivated resulting in the curve crossing above the zero line. Subsequently his motivation returns to neutral, approaching the zero line.

In summary,

- a completely successful response will have each of P_1, P_2 and P_3 equal to exactly +1, whereas

- a completely unsuccessful response will have each of these values equal to exactly 0, and

- a completely counter-productive response will have each of these values equal to exactly –1.

9 Specifying Required Responses

The previous sections discuss the Basis Responses, the means of calculating the Measures of Response once the Target Response Characteristics are known and a way of graphically combining the MoRs with Required Responses. It is this combination process that generates the Measures of System Effectiveness (MoSEs) which can be used in analysis.

Whilst a lot has been said about the Required Responses, it is important to illustrate the detail to which these need to be specified in order for the process to work. Without a suitable amount of detail it will not be possible to bound the magnitude, duration and recovery time requirements, and without these it is impossible to calculate the P_1, P_2 and P_3 P-vector. To quantify these it necessary to refer to a more detailed layer of the scenario or vignette and engage the military community.

Consider the following task -- deter people from moving towards a defender.

[3] Note in Sections 11.7 to 11.7 it was stated that the values of P_1 to P_3 were in the range –1 to +1 and this is because undesirable responses will generate negative values using this methodology.

Figure 14 illustrates how this task may be better defined. Consider a defender, marked **D,** and any target, marked **T**. A polar co-ordinate system can be used to describe the position, velocity and so on of each.

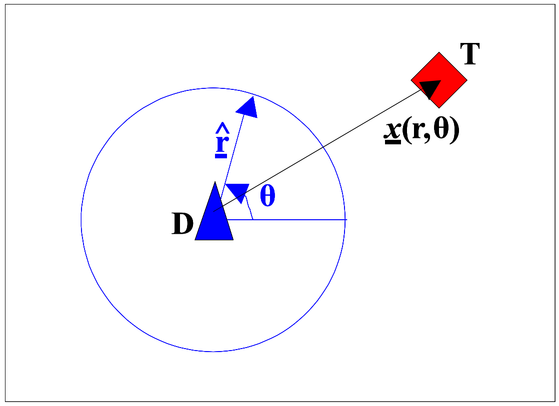


Figure 14 : *Scoping Required Responses.*

A satisfactory outcome is for the target, **T**, to increases its distance (i.e. to move along any of the vectors $\underline{\mathbf{V}}_{\mathbf{I}}$ -- this is explained more fully in Annex E of ref. [1] – the vector defining both a direction and a velocity). A less satisfactory outcome is for the target to stay where it is; that is to say the position remains constant and the velocity is zero. An unsatisfactory outcome (indeed, a counter-productive outcome) is for the target to move along any of the vectors **Q**, i.e. the target approaches$_i$. In this case there is both direction and velocity but these are towards the defender, **D**.

These three conditions relate to influencing mobility, the first of the seven Basis Responses, and they can be written in terms of vector inequalities (see Annex E of ref. [1]) which are measurable responses.

It is necessary, therefore, for a detailed statement of RRs to be made for each and every phase of a mission and for these to identify the responses sought from the various targets under consideration. For some targets the RR may be completely different to that of other targets. For instance, the RR for a leader with whom you wish to communicate will be different from the RR from a bystander whom you wish to disperse. The same device or weapon, used in the same way on the same day needs to be considered in terms of all of the likely RRs.

Thus, a weapon/environment/target combination will lead to a calculable MoR, which can then be compared with these RRs to generate an MoSE.

10 Measures of System Effectiveness

Graphically combining the RRs with the MoRs presents a way of calculating the P-vectors: P_1, P_2 and P_3. Together these form the MoSE. In Sections 11.7 to 11.7 and Section 11.7 an area weighted calculation which generates the full P-vector (whether positive or negative) was outlined.

A P-vector can be calculated for each task or each phase of a mission and for different targets and different weapons. A comparison of competing P-vectors then becomes a task for military commanders, or equipment procurers or technologists (or whatever group uses this methodology).

Consider a task in which there are four weapon options for a given threat.

Table 1 : *Comparing the P-vector values.*

CASE	WEAPON	P_1	P_2	P_3
1	Do nothing	0	1	1
2	NLW 1	0.6	0.4	0.8
3	NLW 2	0.8	0.7	0.5
4	Lethal Force	1	0	0.95

Case 1 – Do Nothing

By doing nothing the targets remain unaffected and the Task Objective of the mission is not achieved. As a result P_1 is equal to zero. As nothing has been done there is no change to the situation and, therefore, nothing to reverse. This has the result of achieving the Target Constraint of reversibility by a certain point resulting in a P_2 equal to +1. Consequently no bystanders or unintended targets are effected either and, as a result P_3 is equal to +1 also.

Case 2 – Use NLW 1

The analysis of this NLW yields a P-vector = (0.6, 0.4, 0.8). That is to say that some of the Task Objective is met, with moderate reversibility in the required time and with very little collateral effect.

Case 3 – Use NLW 2

This time the P-vector = (0.8, 0.7, 0.5) which means that most of the Task Objective is met with somewhat less reversibility than Case 2 in the required time but with significantly greater collateral effect.

Case 4 – Lethal Force

The P-vector = (1.0, 0.0, 0.95) which means that the Task Objective is completely and irreversibly met and there may be small collateral effects (eg. some risk of hitting bystanders as a result of inaccurate aiming).

Although this example considers P values in the range of 0 to +1, it is important to remember that these values are not probabilities, and counter-productive outcomes generate values in the range –1 to 0.

The information provided by the above analysis may be of interest to the various user communities described below.

10.1 The Military Commander

It is not envisaged that a military commander would use this methodology directly when actually conducting an operation. However, it may be useful during training prior to deployment where the commander wishes to gain an appreciation of the effectiveness of various NLWs with which he may be equipped. With this knowledge or awareness, he would be in a better position to assess his options when deployed. For example, depending on the particular phase of a mission the commander may decide to do nothing (case 1), or to employ some NLW (either case 2 or 3) or to use lethal force (case 4). The commander makes the decision based on judgement and an assessment of the best course of action given the precise circumstances at that point in time and the likely course of events based on experience.

If the commander decides that an NLW is required the P-vectors suggest that NLW 1 is less likely to achieve as much success as NLW 2, and NLW 2 looks better than NLW 1 when reversibility within a particular time is sought, but many more unintentional targets are effected by NLW 2 than are by NLW 1. The commander then has to make a decision based on skill, experience and judgement. These decisions will be based on the commander's own character, preferences, skills, and the Rules of Engagement in force at the time.

10.2 Requirement and procurement officials

The same table of P-vectors may assist requirement staffs and associated procurement/ acquisition agencies in identifying a capability gap with current NLWs and the setting of new NLW performance characteristics. For example, a new NLW could be required to generate a new MoSE P-vector between NLW 1 and NLW 2. The executive may then call for the development of a new NLW with a P-vector more like (0.7, 0.6, 0.8). By doing so they will be filling a capability gap in the fighting ability of their forces.

10.3 The force planners

Staffs concerned with the generation and deployment of military forces may use similar tables of P-vectors to decide on the mix of NLWs necessary to be deployed for a certain operation. In addition, they could determine complementary NLW mixes among forces in multi-national operations.

10.4 The research community

The research community may use the same table of P-vectors to guide their work to improve the performance of, for example, NLW 2 in terms of its collateral effect with a view to increasing the value of P_3. In this case, this would lead to NLW 2 outperforming NLW 1.

It is important to recognise that for each of the above user communities, the methodology generates MoSE P-vectors that can be used for decision making purposes. The methodology does not replace any of the expert judgements, decisions or skills that each of these communities has but does provide a means for each to make the most of their skills and to do so in a robust and meaningful fashion.

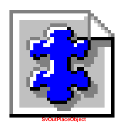
This methodology leads to means which can help, but not replace, experts and provides those experts with better information than they would have had otherwise.

11 Aggregation

At this point the MoSE will exist in the form of a matrix of seven Basis Responses versus three P-values; the Operational Objective (P_1), the Target Constraint (P_2) and the Collateral Constraint (P_3). This 7 by 3 matrix contains a lot of information.

Although this can be very useful, if the seven Basis Responses can be aggregated in some meaningful manner, it may be possible to use a more compact form of the data to impart some similarly important information. At this point it is very important to remember that the values of the Basis Responses <u>are not probabilities</u>. The Basis Responses range from –1 to +1, so schemes designed to aggregate probabilities are of no use here.

A possible, although not exclusive, aggregation scheme is the following:



(1)

This mathematical form has the property that is reduces the 7 by 3 MoSE matrix into an aggregated 1 by 3 MoSE P-vector and the values of the vector elements are in the range –1 to +1. Thus, undesirable or counter-productive responses have a detrimental effect on the calculation and desirable responses have a productive impact. Naturally, some of the detail that could help commanders, procurers, planners or researchers is lost in this aggregation, but it does simplify the impression of good, indifferent or bad MoSE.

In conclusion, it has to be stressed that this is one possible functional aggregation. Other forms of aggregation could be more beneficial and, once again, this is a topic that should be recommended for any NATO follow-on study.

12 Measures of Operational Effectiveness

This, as indicated in Figure 1, is beyond the scope of this NATO study. However, the following section is included as an indication of what can be done in future refinements of this methodology and what needs to be done in terms of model developments if such an outcome is desired.

It is possible (although not necessary) to move from the MoSE P-vectors (P_1, P_2, and P_3) to single numbers. Similarly, it is possible to aggregate the different MoSEs of an operation by taking into account the MoSE 7-by-3 full matrix for each of the higher level Required Outcomes. In order to do this, it is necessary to carefully consider the scenario and score the relative importance of the different Basis Responses. Without making such a judgement, it is impossible to perform the comparative process outlined in Section 11.7, above.

To calculate MoOEs it is necessary to generate Required Outcomes (ROs) for a particular mission or scenario, and to do so it is necessary to consider an event and action time line. This time line consists of a number of tasks of military value, whether actions take place sequentially or concurrently. To illustrate this consider the scenario outlined in Section 12.1 below, the protection of a temporary Brigade and Battalion Headquarters.

12.1 An Example Scenario

The following scenario, depicted schematically in Figure 15, illustrates the process for analysing a scenario as described above in order to support calculations using the MoE Framework, which will be illustrated in the following chapter.

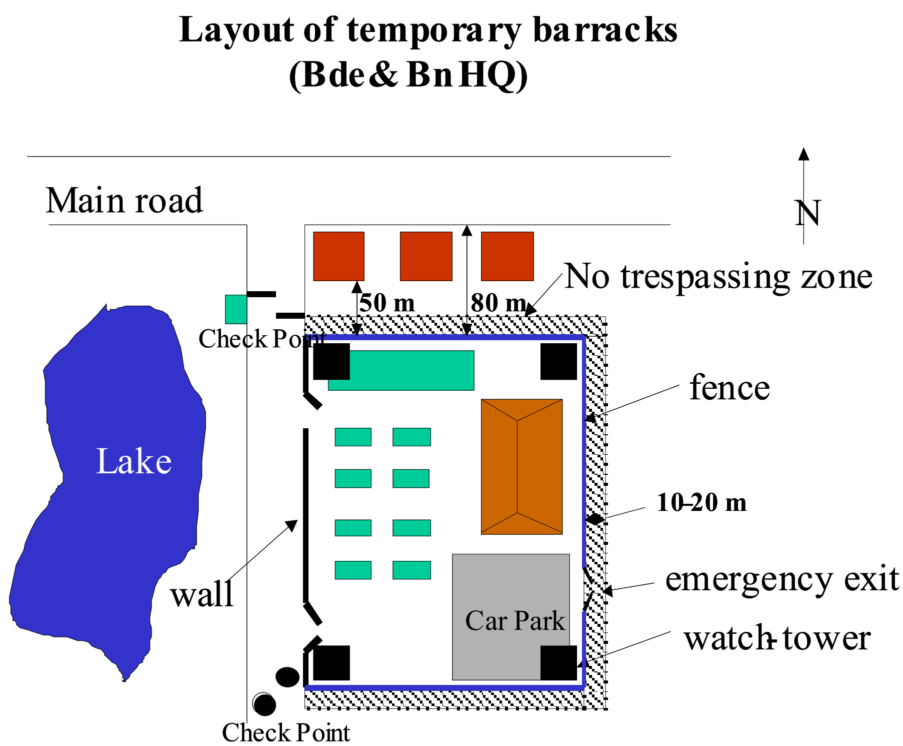


***Figure 15 :** Schematic of scenario.*

Within the perimeter of the camp’s fence there are watch-towers at each of the corners, a sizeable permanent building along the eastern side, various temporary structures, and a car park with vehicles. Just outside the perimeter a 10-20m no trespassing zone is maintained, and check points are manned along the side road that connects with the main road that is about 80m to the north of the camp.

The potential threats are two-fold. First, there are low-level threats from the local population that could include potential break-ins for attempted thefts, individuals carrying small arms, and group activities (likely to include a mix of men, women and children; expected to be overt and relatively uncoordinated; and possibly including some unfriendly actions – such as stone throwing – if the situation degenerates). Second, there are higher-level threats from the former warring factions, who possess mortars, grenades, and automatic weapons and who may attempt to approach covertly and undertake actions against the HQ (to include threatening lives, seizing weapons, destroying equipment, or limiting freedom of action).

When the scenario is considered and analysed it is possible to derive distinct phases.

Phase 1: Deter access to the no trespassing zone.

Phase 2: Phase 1 fails, and attempts are made to enter the No Trespassing Zone. The objective of Phase 2 is to prevent direct attack of the compound perimeter (wall and fences). For the purpose of this experiment, we are no longer considering the threat of mortar attack.

Phase 3: If Phase 2 fails and there is a direct threat that the perimeter may be breached. The objective is to prevent the breach of the perimeter and access to the compound.

Phase 4: Phase 4 occurs if Phase 3 has failed and the perimeter is breached with subsequent access to the compound. The objective is to secure the compound.

Each of these phases occupies a part of an event time line. Within each phase a number of tasks, and there may be many, can be identified (see Table 1).

Each task may be thought of as a combination of Basis Responses. Consider the following examples.

- A task such as “disperse a crowd of people within ten minutes” could be thought of as being made up from “mobility” and “cohesion”.

- A task such as “direct a crowd to a particular point” could be thought of as being made up from “mobility”, “cohesion” and “communication”.

Once each task of a particular phase is considered in this way, the relative importance of each of the Basis Responses, in that phase, can be assessed. This can use sophisticated models (where available), wargames or military judgement. The aim is to produce a ranked order of relative importance. Of course, this is not to say that more sophisticated models can’t be used to determine the impact of a series of responses; this is just another way.

Once this ranked order of importance is determined the same models, games or judgements can be used to assign a relative weighting factor. Both of these actions are depicted in Table 1 by the numbers enclosed in ellipses and the values enclosed in rectangles respectively.

Such score cards help to identify key characteristics that a NLW or conventional weapon should possess for this phase of this mission. In this example, in Phase 2 there is a significant emphasis on influencing the mobility of the targets, then influencing the physical function of vehicles or weapons, then influencing the cohesion or dispersal of groups and so on. Such an analysis can assist in weapon selection and provide a means of down selecting between a choice of weapons where such choices exist.

Table 1: A score card for establishing the importance of tasks on a time line.

Basis Response Effect on Enemy	Phase 1		Phase 2		Phase 3		Phase 4	
Mobility	1	0.40	1	0.30	3	0.13	1	0.30
Communication			6	0.08	5	0.08	6	0.08
Physical function	5	0.05	2	0.20	1	0.35	3	0.13
Sense and interpret (disrupt / disorientate)			7	0.05	5	0.08	6	0.08
Group cohesion (disrupt / disperse)	4	0.14	3	0.13	5	0.08	2	0.18
Identification	3	0.16	5	0.11	2	0.18	3	0.13
Motivation	2	0.25	3	0.13	4	0.10	5	0.10

The example is fully worked through in ref. [1], and it illustrates how it is necessary to:

- consider the course of events which define any particular mission, scenario or vignette, then
- define precisely the various possible outcomes for each of the seven Basis Responses, then
- identify which of these outcomes forms the Required Responses, then
- quantify the magnitude, duration and recovery time associated with each of these, then
- perform a weapon selection, apply the appropriate environmental factors and consider the use of the weapon against the chosen targets.

A comparison of the resulting MoRs with the scenario/phase/task specific RRs as indicated in Section 11.7 then generates the MoSE.

The MoSEs can change given the same combination of weapon, environment and targets but depending on the phase of an engagement, and this is identified through an analysis of the time lines associated with a particular operation. The suitable comparison of the MoSEs and the ranked and weighted score cards, such as the above, will lead to meaningful MoOEs.

Finally, it is important to recognise that the following actions may take place:

- the use of a weapon once in isolation
- the use of one weapon type more than once sequentially
- the use of one weapon type more than once concurrently
- the use of more than one weapon type sequentially
- the use of more than one weapon type sequentially but in a different order
- the use of more than one weapon type concurrently.

The current SAS-035 activity only addresses the first of these. The remainder are MoOE issues. It is recommended that any NATO follow-on study address some of these operational issues.

13 Discussion

The analysis conducted during SAS-035 focused on effects that have a magnitude, duration and recovery within operationally meaningful time scales. Although issues arising from long-term effects are acknowledged as important and relevant, these long-term effects are considered to be outside the scope of SAS-035 analysis. A comprehensive study of NLWs should be encouraged to scope and address these long-term issues and provide some guidance on the best way to include these considerations.

The analysis conducted during the SAS-035 study considered all of the following matters in some detail.

- The study asserts that the reason extant models do not capture NLWs well is due to the limitations in their time-varying assessment of target responses, especially target recovery in a tactically relevant time.
- This study has developed a methodology that enables the effectiveness of NLWs to be assessed at the system level.
- This methodology supports comparisons of NLWs versus NLWs, and comparisons of NLWs versus lethal systems, and comparisons of both lethal systems and NLWs versus doing nothing.
- The methodology assesses effectiveness in three forms:
- Task accomplishment

- Constraint satisfaction vs. the target

- Constraint satisfaction vs. own force, non-combatants, and infrastructure/environment

- The methodology can be used for decision support, but decision making remains a command responsibility.

Some anticipated user communities were identified earlier, but a more inclusive list may be:

- Military field commanders

- Force generators

- Concepts, doctrine, and requirements staff

- Procurement staffs

- Research and development staff

- Modelling and simulation

- Operational research

- Training.

Implementing the methodology will require an understanding of target response characteristics. At present, available data is very limited (especially human effects characterisations), the development of additional data is very much needed but a problem at this time. The methodology does provide a framework for those analysis target characterisations and target responses with types of data that are needed and the context within which that data will be used.

It is suggested that the framework should be amenable to the physical NLW effects and responses. Although it is thought that this framework could be extended to cover psychological effects, the efficacy of this framework in this context would require significant validation.

NLWs are not a service-specific issue. While the examples shown in this report focus on land applications, there are similar opportunities for air and maritime applications.

By combining the taxonomy, complete with up to date TRL values, and the sub-functional tasks it should be possible to develop tools which can assess the effectiveness of a selection of similar weapons for a particular mission, operation, scenario or vignette.

The methodology displays the following strengths and weaknesses.

- Strengths

It is relevant to both lethal and non-lethal weapons and systems.

It is a simple way for comparing very different weapon types through the Basis Responses.

It provides a number of communities with a framework which enables them to better specify either their tactical or operational requirements in a measurable and exercisable manner.

- Weaknesses

The values are relatively difficult to aggregate, and a number of possible ways can be identified but each would require some research and consideration.

The methodology is "new" and needs a thorough assessment and verification and validation in the traditional sense.

The methodology relies upon the creation of a set of Target Response Characteristics, which enable different weapon types to be compared. The lack of these data is a severe limitation to the further development of this methodology into a workable and useable tool.

The Basis Responses are not likely to be truly independent variables and this means that a number of possible interpretations could be possible for any given situation. Once again, more research would be necessary to quantify the problems associated with this assertion.

The methodology developed during the SAS-035 study provides a means of establishing the Measures of System Effectiveness of NLWs and conventional weapons. It is robust to minor changes and does provide a means of trading various courses of action off against one another.

14 Conclusions

The following form the main conclusions from this methodology.

1. All tasks identified in scenario analysis (and the national studies SAS-035 drew from) can be described in terms of a few very simple responses called the Basis Responses.
2. The Basis Responses provide the means for comparing required responses with calculated MoRs in order to calculate system effectiveness.
3. Each Basis Response consists of three factors; magnitude, duration and recovery.
4. Each of these factors is influenced by the tasks associated with particular phases of a mission, operation, scenario or vignette. These task specific factors constitute the Required Responses.
5. It is anticipated that complex weapon Measures of Performance can be converted into these Basis Responses through the definition of appropriate time varying mathematical transfer functions called the Target Response Characteristics.
6. The functions comparison of the time varying Measures of Response with the task varying Required Responses yields the Measure of System Effectiveness.
7. The use of more than one weapon, whether sequentially or concurrently, and the analysis of the combined resultant MoSEs with the higher level Required Outcomes of a mission at the operational level rather than at the task level, constitutes Measures of Operational Effectiveness. (These have not been explored as part of this study.)

8. The absence of target response data is a significant inhibitor to the implementation of this methodology.

15 Recommendations

1. The barrier to NLW effectiveness assessments is now not the absence of a methodology but the lack of target effects/target response data, both human effects data and material effects data. Hence, nations should be encouraged to generate data in an appropriate format, as outlined by this study.
2. The need to implement the methodology – by developing software – is critical to meet the needs of user communities. A software development and maintenance plan should be drawn up, endorsed, and funded.
3. SAS-035 confirms the need for a follow-on study as called for in the NATO NLW Roadmap. It is recommended that this study should have terms of reference (TOR) as per ref. [1],
4. It is important to ensure that the SAS-035 follow on work is well integrated into the NATO planning process. This is especially important to ensure relevance to future NATO operations and to transformation efforts.
5. An Executive Seminar should be conducted. The purpose is to capitalise on the work of this and other ongoing NATO NLW studies, increase awareness of NLWs, and obtain feedback – e.g. on military requirements – for use in subsequent efforts.

16 Evaluation Models

By Pierre Fournier

A survey of models applicable to NLW studies was conducted at the request of SAS-035 and is included in Annex G of ref. [1]. This survey was also published in ref. [4]. The findings of this survey are reproduced in this chapter. This survey identified a number of models, but also a few empirical studies conducted in some of the countries participating to SAS-035.

Successful modeling of NLW effects will depend on the availability of target effects data. For obvious practical and ethical reasons, target effects data will be especially difficult to obtain in the case of anti-personnel applications where physical and psychological effects of NLW on humans are required for meaningful modeling.

One of the areas where DRDC could play a role in future NLW work and contribute to future developments of SAS-035's methodology is with the characterization of anti-personnel kinetic NLW. Physical head and torso models, and numerical models for head and torso (the LS-DYNA models in Table 2) developed to study Behind Armour Blunt Trauma (BABT) could be used with little, if any, modifications to study and characterize the effects of kinetic NLW. These models are available in DRDC-Valcartier. As with lethal weapons, the difficulty resides in relating a type of trauma with the physical parameters of a given impact.

Table 2. Types of models for NLW studies.

MODEL FUNCTION	FUNCTIONAL AREA	MODEL NAMES
Target Response Characteristics	Anti-personnel	LS-DYNA Human Head numerical model LS-DYNA Human Torso numerical model Physical Head model Physical Torso model
Target Response Characteristics	Anti-materiel	EMPDREV
Measure of Operational Effectiveness	Anti-personnel and Anti-materiel	ModSAF CAEn

TRC for a specific anti-materiel applications can also be obtained from the EMPDREV model available in DRDC-Valcartier. This model calculates the probabilities of failure of a piece of electronic equipment such as a radar or a computer when it is exposed to an Electromagnetic Pulse (EMP). The source generating the EMP can be nuclear or not. However, EMPDREV requires some more development before it can be used. A more elaborate discussion of the EMPDREV model can be found in [4].

The models and experimental data discussed so far address the TRC and MoR. In future work, when the focus will be on Measure of Operational Effectiveness, wargaming and combat simulation models like ModSAF and CAEn could be used to assess the effectiveness of NLW in an operational context. That is, the objective will be to assess NLW beyond the single use of a single NLW, and to look at multiple use of one or several NLW.

Table 3 to Table 6 list evaluation models identified in other countries during SAS-035's survey. Table 3 gives a short list of generic methods which support the evaluation of the feasibility of the MOE framework in SAS-035.

***Table 3.** Generic methods/concepts which support the evaluation of feasibility of MOE framework in SAS-035.*

Model Name	Description	Country of Origin
Bonus Malus method	Conceptual model	NL
Frame of Reference NLW	Evaluation instrument based on Multi-Criteria Analysis model	NL

Table 4 lists selection and database tools. The selection tool is TIMS, which is an Extranet environment to access NLW information. The other two database tools in Table 4 were developed for lethal weapons, but they could be adapted to NLW.

Table 4. *Selection or Database tools.*

Model Name	Description	Country of Origin
Technology Information Management System (TIMS)	Extranet environment and portal to NLW information	NL
DataBase Weapon Indicators (DBWI)	Database tool for lethal weapons	NL
US Weapons Database	Initially set-up for lethal weapons but with potential for extension to NLW (used as basis for NLW database	US

Table 5 is a list of simulation tools at the tactical and the operational levels. Most of these models were developed for lethal weapons. Models of NLW and of target reactions to NLW will have to be developed to study NLW at the tactical and operational levels. This, in turns, requires an understanding of the target response to the effects of NLW.

Table 5. *Simulation tools (tactical/operational level).*

Model Name	Description	Country of Origin
Crowd Control Spreadsheet Model	Model on NLW deployment for Crowd Control (SAS-035, feasibility stage MOE frame, Crowd Behaviour should be incorporated in the model	UK
Integrated Unit Simulation System (IUSS)		US
Joint Conflict & Tactical Simulation (JCATS)		US
Joint Tactical Level Simulation (JTLS)		US(?)
Johannes model	Deterministic time-stepping land combat model, centered around the C3I process	DK
KIBOWI	Command and staff training instrument up to division level). Implementation of NLW will require huge effort.	NL
EON	System specification of non-lethal engagement simulator	NL

Finally, Table 6 gives a list of technical evaluation studies conducted by means of experiments in the Netherlands. This list is not exhaustive since other countries have also conducted experiments with NLW and briefed their results at the Second European NLW Symposium [5].

Table 6. *Technical evaluation (system-level studies) by means of experiments.*

Model Name	Description	Country of Origin
Evaluation of non-lethal hand grenades	Investigated for releasibility in SAS-035 database development	NL
Dose-effect relationship for infrasound		NL
HPM effects and measurements		NL
How to compose a PsyOps message	Determination of influence on group attitudes and behavior	NL
Application and effect of net technology		NL
Odorous substances evaluation		NL

16.1 The Map Aware Non-uniform Automata

The Map Aware Non-uniform Automata (MANA) model was developed by the New-Zealand Defence Technology Agency (DTA). MANA is designed as a Complex Adaptive System (CAS) and falls into the category of cellular automaton combat models. MANA is designed for use as a scenario-exploring model and is intended to address a broad range of problems. More information on MANA is provided in MANA's documentation [6].

The Operational Research Group in DRDC Valcartier recently obtained MANA and it is used for two different projects. It is clear from this recent experience gained with MANA that it can be used for NLW studies, provided that meaningful data on physiological and psychological effects of NLW on humans can be fed to MANA. It is unknown whether MANA was used to model NLW, but MANA was used in DTA and in other research agencies to study situations in which NLW could play a role (see refs. [7] to [9]).

17 General Conclusion

An effects assessment framework and a number of models potentially useful for NLW studies were presented in this Technical Note. At the conclusion of its mandate, the SAS-035 Study Team recommended a follow-on study to address the Verification and Validation of the framework and the extension of the framework to Measures of Operational Effectiveness. It was recommended that this follow-on study team also identifies the type of data that is required by the framework. At the time of writing this Technical Note, the formation of an exploratory team to continue the work of SAS-035 was approved by the SAS Panel, and The Technical Cooperation Program (TTCP) also formed a study team to develop research designs for the assessment of NLW human effects.

18 References

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19 List of symbols/abbreviations/acronyms/initialisms

CAEn	Close Action Environment
DND	Department of National Defence
DRDC	Defence Research and Development Canada
DTA	Defence Technology Agency
MANA	Map Aware Non-uniform Automata
ModSAF	Modular Semi Automated Forces
MoP	Measure of Response
MoSE	Measure of System Effectiveness
NATO	North Atlantic Treaty Organization
NLW	Non Lethal Weapons
ORD	Operational Research Division
PWC	Physical Weapon Characteristics
RR	Required Response
RTO	Research and Technology Organization
SAS	Studies, Analyses and Simulations
TRC	Target Response Characteristics
TTCP	The Technical Cooperation Program

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Annex H. Non-Lethal Weapon Technology Taxonomy

1 Non-Lethal Weapon Technology Taxonomy

This Taxonomy categorizes possible NLW technology types and was developed by the NATO SAS-035[1] study which is based on the US Joint NLW Directorate Taxonomy. Specific NLW systems that use these and other technologies must comply with treaty and legal obligations.

Electro-Magnetic	Chemical	Acoustic	Mechanical Kinetic	Ancillary
Electrical Pulsed Current Direct Current **Radio Frequency** EMP Wide Band Ultra Wide Band **Microwave** High Power Microwave **Millimetre Wave** **Infrared** Lasers COIL* CO_2** HF/DF*** Solid State **Visible** Lasers Lights **Ultraviolet** Lasers **X-Rays**	**Obscurants** Rapid Hardening Agents Smokes **Reactants** Super-Corrosives Combustion Altered Viscosity Combustion Altered Fuel-Air Lubricant Contaminants Depolymerizers Embrittlers Emulsifiers **Malodorants** **Riot Control** **Anti-Traction** Lubricants Surfactants **Foams** **Thermobaric** **Nano-Particles**	**Audible** (20 Hz-20 KHz) **Audible/Optical** Flash Bangs **Ultrasound** (>20 KHz)	**Barriers** **Entanglements** Nets **Cloggers** **Blunt Impact** Projectiles Velocity Adjusting Water Stream **Vortex Ring Gun**	**Marker** Dyes Fluorescent Paints Taggers **Non-Lethal Casings** Frangible Combustible **Encapsulants** Micro-encapsulation

* COIL - Chemical Oxygen Iodine Laser
** CO_2 - Carbon Dioxide
*** HF/DF - Hydrogen Fluoride/Deuterium Fluoride

[1] NATO Research and Technology Organization. Studies Analysis and Simulation Panel. Non-Lethal Weapons Effectiveness Assessment. Report no. RTO-TR-085, 1 Oct. 2004. CD-ROM. Neuilly-sur-Seine, France: NATO RTO, 2004.

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14. ABSTRACT

The aim of this overview study is to recommend the Non-Lethal Weapon (NLW) research and development that Defence Research and Development Canada (DRDC) could conduct over the next decade (and possibly beyond) in response to emerging defence and security NLW requirements. It summarizes the DRDC perspective of NLW technologies, which includes non-lethal applications of electro-magnetic and acoustic directed energy. The study shows that by channeling existing expertise and effort, DRDC could, over time, provide the Canadian Forces with science and technology knowledge on the effects, operational effectiveness and counter-measures of selected, emerging NLW technologies.

La présente étude d’ensemble a pour objet de recommander les travaux de recherche et développement sur les armes non létales (ANL) que Recherche et développement pour la défense Canada (RDDC) pourrait effectuer au cours des dix prochaines années (et peut être au delà) pour satisfaire aux nouveaux besoins d’ANL en vue d’assurer la défense et la sécurité. Elle résume la perspective de RDDC sur les technologies d’ANL, notamment les applications non létales de l’énergie électromagnétique et acoustique dirigée. L’étude montre que si elle canalise l’expertise et le travail actuels, RDDC pourrait, au fil du temps, fournir aux Forces canadiennes des connaissances scientifiques et technologiques sur les effets, l’efficacité opérationnelle et les contre-mesures liées à certaines technologies nouvelles en matière d’ANL.

15. KEYWORDS, DESCRIPTORS or IDENTIFIERS

Defence R&D Canada

Canada's leader in defence
and national security R&D

R & D pour la défense Canada

Chef de file au Canada en R & D
pour la défense et la sécurité nationale

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