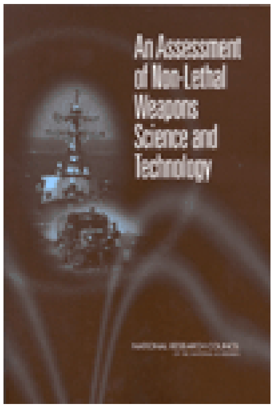

An Assessment of Non-Lethal Weapons Science and Technology

Committee for an Assessment of Non-Lethal Weapons Science and Technology, National Research Council

ISBN: 0-309-50956-4, 198 pages, 6 x 9, (2003)

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Science and Technology

Naval Studies Board

Division on Engineering and Physical Sciences

NATIONAL RESEARCH COUNCIL
OF THE NATIONAL ACADEMIES

THE NATIONAL ACADEMIES PRESS
Washington, D.C.
www.nap.edu

THE NATIONAL ACADEMIES PRESS 500 Fifth Street, N.W. Washington, DC 20001

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This study was supported by Contract No. N00014-00-G-0230, DO #7, between the National Academy of Sciences and the Department of the Navy. Any opinions, findings, conclusions, or recommendations expressed in this publication are those of the author(s) and do not necessarily reflect the views of the organizations or agencies that provided support for the project.

International Standard Book Number 0-309-08288-9

Copies available from:

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Preface

As part of the nation's national security strategy, naval forces remain deployed throughout the world, engaged in or ready to support operations ranging from training exercises with joint and allied coalition partners, to humanitarian relief efforts, to peacekeeping and peace enforcement, to combat. Non-lethal weapons provide one means by which expeditionary forces can accomplish their missions, particularly in urban areas, with a reduced likelihood of death and injury to non-combatant civilians who might be encountered, for example, in hostage rescue or human shielding operations. As a result of the National Defense Authorization Act of 1996 and because of Marine Corps initiative and experience, the Commandant of the Marine Corps was designated the executive agent for joint Service research, development, testing, and evaluation of non-lethal weapons and non-lethal weapons technologies.

Operating with a yearly budget of approximately $25 million, the Joint Non-Lethal Weapons Directorate (JNLWD) is executing these responsibilities. Less than $1 million of this amount is used to support new technology development. Currently, the role of the JNLWD in areas related to information warfare and psychological warfare and with respect to single-Service activities is limited to coordination and integration. At issue for the Department of the Navy is to what extent and in what areas Navy-sponsored science and technology should provide a research base for developing non-lethal weapons capabilities.

Non-lethal weapons consist of a diverse array of individual weapons that minimize fatalities and undesired damage to property and the environment. They function in three realms: those of (1) counterpersonnel objectives, which include controlling crowds; incapacitating individuals; denying areas to personnel; and clearing personnel from facilities, structures, or areas of operation; (2) countermateriel objectives, which include denying areas to vehicles, vessels, or aircraft, and disabling or neutralizing vehicles, vessels, aircraft, or equipment; and (3) countercapability objectives, which include disabling or neutralizing facilities and systems and denying use of weapons of mass destruction.

Non-lethal weapons technologies cover a broad spectrum, including areas related to the development of acoustics systems, chemicals (e.g., antitraction materials, dyes, markers, and malodorants), communications systems, electromagnetic and electrical systems, entanglement and other mechanical systems, information technologies, optical devices, non-penetrating projectiles and munitions, and many others. Combinations of non-lethal and lethal weapons are possible. Synergy of non-lethal weapons with psychological, information, and/or electronic warfare in a networked fashion could be especially effective. As non-lethal weapons are developed and acquired, it is especially important that training, delivery, deployment, control, logistics, maintenance, and doctrine for use are in hand. Forward-deployed, distributed naval forces offer great potential for timely use of non-lethal weapons in a variety of scenarios.

TERMS OF REFERENCE

At the request of the Joint Non-Lethal Weapons Directorate and the Office of Naval Research, the Naval Studies Board of the National Research Council conducted an assessment of non-lethal weapons science and technology that addressed the following terms of reference:

- Review the previous non-lethal weapons studies and initiatives, and assess their response along with any DOD response.
- Review the current and planned non-lethal weapons program of record as executed by the Joint Non-Lethal Weapons Directorate under the charge of the Commandant of the Marine Corps.
- Review and identify current and planned Department of the Navy science and technology programs (budget categories 6.1-6.3) that currently do or could in the future contribute to the development of non-lethal weapons' capabilities.
- Identify technology developments (including synergies of technologies) that show promise for enhancing existing non-lethal weapons capabilities or developing new non-lethal weapons capabilities for use by naval expeditionary forces. These capabilities should not be limited to weapons exclusively, but also should include training, handling, control, delivery, logistics and maintenance support, countermeasures, and doctrine (or operational concepts) development.
- Identify programs that may represent duplication of effort or could benefit from leveraging of resources.
- Recommend science and technology program actions that might be initiated by the Office of Naval Research in support of naval expeditionary force needs for non-lethal weapons.

This final report reviews and projects technology developments; identifies promising areas for research in science and technology; identifies duplication or leveraging opportunities; and addresses broader issues related to training, handling, control, delivery, logistics and maintenance support, countermeasures, and development of operational concepts.

COMMITTEE MEETINGS

The Committee for an Assessment of Non-Lethal Weapons Science and Technology first convened in February 2001 and held additional meetings and site visits over a period of 7 months:[1]

- *February 1-2, 2001, in Washington, D.C.* Organizational meeting: Joint Non-Lethal Weapons Directorate briefings on historical perspectives, current capabilities, joint concepts, existing Service mission need statements, assessment of science and technology needs, previous studies, airborne tactical laser advanced concept technology demonstration (ACTD), and foreign exchange agreements.
- *March 6-7, 2001, in Washington, D.C.* Marine Corps Combat Development Command briefings on Marine Corps non-lethal weapons (NLWs) concepts and requirements; Marine Corps Warfighting Laboratory briefing on non-lethal weapons experimentation; Marine Corps Systems Command briefing on non-lethal weapons acquisition management; Headquarters U.S. Marine Corps briefing on the Marine Corps perspective on directed energy; U.S. Army Training and Doctrine Command briefing on weapons requirements, concepts, and experimentation; U.S. Coast Guard Headquarters Support Command briefing on current and planned use of NLWs; Naval Sea Systems Command (NAVSEASYSCOM) briefing on NAVSEASYSCOM perspective on NLWs; the Secretary of the Navy's Antiterrorism/Force Protection Task Force briefing on actions stemming from the attack on the USS *Cole*; and U.S. Army Program Manager for Mines, Countermines, and Demolition briefing on the non-lethal weapons program for mines, countermines, and demolition.
- *April 3-4, 2001, in Washington, D.C.* Naval Research Laboratory briefing on high-energy lasers and high-power microwave/millimeter-wave source technology; U.S. Army Soldier and Biological Command overview of non-lethal weapons science and technology; Marine Corps Judge Advocate Division International and Operational Law Branch briefing on legal issues affecting non-lethal weapons policy; National Institute of Justice overview of NLWs; U.S. Joint Forces Command overview of experimentation and technical initiatives related to NLWs and low-collateral-damage weapons; U.S. Special Operations Command

[1]During the entire course of its data gathering, the committee held meetings closed to the public in which it received (and discussed) classified material. Accordingly, the content of this report is limited by restrictions to classification.

overview of non-lethal weapons science and technology requirements, concepts, and experimentation.

- *April 29-30, 2001, in San Antonio, Texas, and Albuquerque, New Mexico.* Site visit to Brooks Air Force Base, Kirtland Air Force Base, and Sandia National Laboratories for briefings on the Air Force non-lethal weapons perspective, overview of non-lethal weapons human effects, Human Effects Advisory Panel, joint non-lethal weapons program Human Effects Center of Excellence, tri-Service radio-frequency/microwave/millimeter-wave bioeffects program, tri-Service laser bioeffects program, antisensor laser (Medusa), infrastructure, vehicle stopper, modeling and simulation effects, active denial technology, and Los Alamos National Laboratory and Lawrence Livermore National Laboratory non-lethal weapons initiatives.
- *May 16-17, 2001, in Washington D.C.* Small group visit to Office of Naval Intelligence for Small Boat Threat Workshop.
- *May 21, 2001, in Aberdeen, Maryland.* Small group visit to Edgewood Chemical and Biological Command.
- *June 12-14, 2001, in Washington D.C.* Deputy Study Chair briefing on 2000 Air Force Scientific Advisory Board study *Technologies to Leverage Aerospace Power in Operations Other Than War*; U.S. Air Force Headquarters Security Forces overview of non-lethal weapons concepts, experimentation, and requirements; Defense Threat Reduction Agency briefing on protecting U.S. Navy ships in foreign ports; Potomac Institute for Policy Studies briefing on Center for Emerging Threats and Opportunities; Mission Research Corporation briefing on pulsed-energy projectile program; U.S. Army Center for Health Promotion and Preventive Medicine briefing on health hazard analyses; Walter Reed Institute for Research briefing on interim total body model; and Science Applications International Corporation briefing on loitering electronic warfare killer ACTD. Also, in an effort to frame potential applications of NLWs for U.S. Navy operations (and the supporting technology options and system concepts to meet those operational needs), the committee held a 1-day data-gathering session with representatives from the Office of the Chief of Naval Operations, the Chief of Naval Operations Strategic Studies Group, the Joint Non-Lethal Weapons Directorate, the Office of Naval Research, the Navy Warfare Development Command, the Office of Naval Intelligence, the Naval Research Laboratory, the Naval Surface Warfare Center Dahlgren Division, the Space and Naval Warfare Systems Command, the U.S. Coast Guard Non-Lethal Weapons Center of Excellence, and the Applied Research Laboratory/Pennsylvania State University.
- *July 16-20, in Woods Hole, Massachusetts.* Committee deliberations and report drafting.

The months between the last meeting and publication of the report were spent preparing the draft manuscript, reviewing and responding to the external review comments, editing the report, and conducting the required security review necessary to produce an unclassified report.

Following completion of the security review a prepublication copy of the report was released to the public on November 4, 2002. Subsequent to that release, it became apparent that the Department of Defense and the Department of State have differing legal interpretations of the Chemical Weapons Convention as it pertains to the development of chemical non-lethal weapons for military purposes. As a consequence, and in recognition that it was not the mandate of the committee to conduct a legal review of the permissibility of non-lethal weapons as it relates to the Chemical Weapons Convention (and other national and international law and treaties), a brief discussion of legal considerations has been excised from the final report. In doing so the committee recognizes that it is of paramount importance that the Department of Defense and the Department of State clarify the legal interpretations of the Chemical Weapons Convention so that both the operational and technical communities can move forward under consistent guidelines.

Acknowledgment of Reviewers

This report has been reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise, in accordance with procedures approved by the National Research Council's Report Review Committee. The purpose of this independent review is to provide candid and critical comments that will assist the institution in making its published report as sound as possible and to ensure that the report meets institutional standards for objectivity, evidence, and responsiveness to the study charge. The review comments and draft manuscript remain confidential to protect the integrity of the deliberative process. We wish to thank the following individuals for their review of this report:

Richard L. Garwin, IBM Thomas J. Watson Research Center,
Larry G. Lehowicz, USA (Ret.), Quantum Research International,
John (Ted) Parker, USN (Ret.), Annapolis, Maryland,
John E. Rhodes, USMC (Ret.), Balboa, California,
Charles F. Sharn, McLean, Virginia, and
Peter R. Worch, Leonardtown, Maryland.

Although the reviewers listed above have provided many constructive comments and suggestions, they were not asked to endorse the conclusions or recommendations, nor did they see the final draft of the report before its release. The review of this report was overseen by John W. Rouse, Southern Research Institute. Appointed by the National Research Council, he was responsible for making certain that an independent examination of this report was carried out in accordance with institutional procedures and that all review comments were carefully considered. Responsibility for the final content of this report rests entirely with the authoring committee and the institution.

Contents

Prologue

September 11, 2001, was a defining day in the history of the United States of America, if not the world. The unprecedented disasters in New York and Washington, D.C., have placed the nation on a wartime footing, and we have formally acknowledged our battle against terrorism. The implications for warfighting and law enforcement have yet to be fully understood, but most would agree that profound shifts in emphasis and investment are likely to come. In rooting out terrorism's infrastructure, there will be times when controlled application of force will be essential and unconstrained violence counterproductive to our strategic goals. Moreover, punishing attacks that destroy the overt support system for terrorists will not be sufficient to weed out well-hidden infrastructure, some of which already resides on U.S. soil. As the immediate emotional circumstances fade, the need to isolate a few individuals, both in the United States and abroad, most likely in and amongst civilian populations, will remain critically important. In that context, non-lethal weapons may play an even greater role in matters of national security.

Of particular concern to the Navy will be yet greater emphasis on base security and force protection as the links between the events of September 11 and the USS *Cole* incident begin to be made. This report addresses those issues but could not fully appreciate the new complexities in which those missions are likely to be executed. For the U.S. Marine Corps the focus on Military Operations in Urban Terrain is likely to take on added importance, with minimization of collateral casualties and damage being of the utmost importance for maintaining fragile coalition relations with Middle Eastern states in particular. This report emphasizes the role of non-lethal weapons for those missions, but the emerging political climate elevates to a strategic level the importance of controlled use of force.

In this milieu, the development and deployment of more capable non-lethal weapons should be given a higher priority. This report was in review on September 11. None of its recommendations have been altered by the events of that day—but the urgency in their acceptance and implementation has.

Executive Summary

The motivation for this report had its origins in the mutual interests surrounding future non-lethal weapon science and technology (S&T) by the Joint Non-Lethal Weapons Directorate (JNLWD) and the Office of Naval Research (ONR). The Committee for an Assessment of Non-Lethal Weapons Science and Technology was asked to assess current and potential areas for S&T investment in non-lethal weapons (NLWs) to support naval expeditionary forces; it found several areas that deserve such investment. In reviewing the program of record for the JNLWD, as also directed by the terms of reference, the committee evaluated the spectrum of activities that turn S&T advances into fieldable and fielded systems. As it explored the many dimensions associated with the transition of NLWs from research and development (R&D) to the field, the committee uncovered a number of areas of concern in the current JNLWD and U.S. Navy efforts related to NLWs. These concerns must be addressed by the Joint Non-Lethal Weapons Directorate, the Navy Secretariat, and the Chief of Naval Operations—or the risk is high that added investments by ONR in non-lethal weapons R&D will be of little value.

NON-LETHAL WEAPONS FOR NAVAL EXPEDITIONARY FORCES

The potential for non-lethal weapons to help meet the overall demands on naval expeditionary forces in the 21st century is clear. As discussed in subsequent chapters, the experiences of the U.S. Marine Corps in the peacekeeping and urban engagement conflicts in the past decade and the challenges to the Navy in sanctions enforcement and port protection offer compelling case studies for the importance of having non-lethal weapons options. The Marines have assumed leadership for developing requirements for clearing facilities and incapacitating personnel via non-lethal means to meet the constraints of rules of engagement in mixed combatant/non-combatant environments.

The Navy's needs for non-lethal weapons options are emerging in several different areas. One of these developed in the aftermath of the USS *Cole* incident of October 2000: comprehensive assessments of force protection measures are starting to generate a notional three-layer architecture for ship protection—an outer zone for assessing and warning of approaching vehicles and personnel (pierside and outboard; above, on, and below the surface); a middle zone for initial engagement to turn away a threat if it is still approaching, at which point non-lethal means may offer the only reasonable alternative to deterring the threat; and a third, inner zone in which lethal force could be employed. In a second area, sanctions enforcement in the Persian Gulf has highlighted the challenges of intercepting and boarding suspect vessels in the midst of heavy commercial traffic and in the face of unknown crew makeup. Non-lethal weapons options could offer a valuable means for interdiction if needed in such environments. A third compelling area of need has been identified by Chief of Naval Operations (CNO) Strategic Studies Group XVIII: that is, NLWs are needed to fully enable the Sea Strike concept by filling important gaps in the spectrum of effects-based targeting. A prime example would be engagements in littoral environments where urban centers are prevalent and minimization of collateral damage is required.

After a decade of successful, but limited, operational experience with NLWs and 5 years of progress by the JNLWD—the directorate was established in 1996 to introduce non-lethal weapons more quickly in response to warfighting needs—the future of NLWs is at a crossroads. NLWs with limited capabilities for individual, highly localized self-defense or combatant isolation are available. Because countermeasures for these capabilities may not be difficult, the demand is growing for more capable systems with wider-ranging effects. The research, development, and acquisition of these more robust capabilities will be well beyond the scope of the current joint program and will have to be integrated into the normal development and acquisition cycle of each of the Services. At the present time, the Department of the Navy is not prepared to carry out these responsibilities.

ADDRESSING THE TERMS OF REFERENCE

The terms of reference chartered the committee to take an extensive look at the area of non-lethal weapons and also asked for an assessment of the impact of prior studies and initiatives as well as an assessment of the capabilities that turn a promising non-lethal weapons technology into a viable operational system. Because the story is complex and the issues called out in the terms of reference are highly interdependent, pointers to key sections of the report addressing each aspect of the committee's charge are provided below for the reader's use.

- *Review and assessment of previous non-lethal weapons studies and initiatives.* Sections 1.1, 2.6, 2.7, 2.8, and 2.9 provide background on policy and directives, operational experience, programs and initiatives outside the Department of the Navy, and studies and conferences. Results accumulated since the establishment of the JNLWD in 1996 are highlighted.
- *Review of the JNLWD program of record.* Section 2.3 describes the directorate's short history, accomplishments, and current programs. The opening paragraphs of Chapter 3 and Section 3.1 discuss the committee's observations and findings based on its review of the current program. Its conclusions and recommendations for the JNLWD program are provided in Sections 4.1 and 5.1, respectively.
- *Review of Department of the Navy S&T programs that do, or might, contribute to the development of non-lethal weapons capabilities.* This issue presented the committee with a challenge. The U.S. Marine Corps has well-established and articulated needs for NLWs, but the Navy had not given much attention to their use until the aftermath of the USS *Cole* incident. As such, the committee spent some time studying the mission needs of the Navy in order to evaluate relevant S&T within the department. Those needs are described in Section 1.2, and current programs that are relevant to them are discussed in Sections 2.4 and 2.5. U.S. Marine Corps programs relevant to non-lethal weapons capabilities are described in Section 2.6. The committee's assessment of needs versus existing S&T programs led to the concerns expressed in its findings on the department's organizational interest (Section 3.4) and its related recommendation (Section 5.4).
- *Identification of technology developments that show promise for enhancing existing non-lethal weapons capabilities or for enabling new ones.* Responding to this task broadened the fact finding of the committee to include the means by which a promising technology is turned into an operational reality. In the process, the committee came to realize that sensor and platform capabilities had to be addressed hand in hand with non-lethal weapons technology development. These considerations are discussed in Sections 2.1, 3.2, 3.3, and 5.3. In looking beyond the technologies themselves, the committee also discovered the shortcomings in current understanding of non-lethal weapons effects and effectiveness. The impact of this issue on warfighter acceptance of NLWs as a useful and integral operational capability is so profound that the committee devoted two of its four recommendations to the issue. These topics are addressed in Sections 2.2, 3.1, 3.2, 3.3, Chapter 4, and Sections 5.1 and 5.2.
- *Identification of programs that duplicate efforts or could benefit from leveraging.* The committee found nothing that raised concerns regarding duplication of effort; the JNLWD has done a good job of ensuring that resources are wisely spent. The principal opportunities for leveraging are presented by sensors and platforms as critical system enablers; related observations and recommendations are provided in Sections 2.1, 3.2, and 5.3.

• *Recommendations for S&T program actions by ONR*. Section 5.3 recommends specific actions to strengthen S&T in four general areas. The recommendations include focused investment and expansion of current programs within ONR (e.g., high-power microwave), leveraging of relevant programs in sensors and platforms, and partnering with the Army for chemical non-lethal weapons development.

STATUS OF NON-LETHAL WEAPONS TECHNOLOGIES: SYNOPSIS OF FINDINGS

The committee undertook a careful survey and assessment of non-lethal weapons technologies across a wide spectrum of phenomenologies—chemical and physical, to physiological and psychological. This survey included a number of classified programs as well as the areas discussed in this unclassified report. The committee identified several S&T areas worthy of ONR's attention:

1. Calmatives and malodorants for controlling crowds and clearing facilities, developed and applied in accordance with U.S. treaty obligations in the Chemical Weapons Convention;[1]
2. Directed-energy systems beyond the vehicle-mounted active denial system (VMADS): high-power microwave (HPM) for stopping vehicles or vessels and solid-state lasers for advanced non-lethal weapons applications;
3. Novel and rapidly deployable marine barrier systems; and
4. Adaptation of unmanned or remotely piloted platforms and targeting/real-time battle damage assessment (BDA) sensors for non-lethal weapons applications.

The committee's review identified positive accomplishments during the past 5 years as well as areas of concern. The following advances are particularly noteworthy:

• *Joint Non-Lethal Weapons Directorate*. The JNLWD, with the U.S. Marine Corps serving as executive agent, was established in 1996. It has achieved noteworthy progress in spite of operating under the combined pressures of high visibility and very modest funding ($20 million to $30 million per year). Examples of its accomplishments include the qualification and transition to acquisition of non-lethal weapons capability sets for deployment by Marines and soldiers; the establishment, in principle, of the process and capabilities for assessing antipersonnel non-lethal weapons effects through the Human Effects Review Board and the Human Effects Center

[1]As noted in the preface, the committee recognizes that it is of paramount importance that the Department of Defense and the Department of State clarify the legal interpretations of the Chemical Weapons Convention so that both the operational and technical communities can move forward under consistent guidelines.

of Excellence; the recent maturing to demonstration of VMADS; and the validation of the first-ever non-lethal weapons joint mission area analysis by the Joint Requirements Oversight Council.

- *Operational experience*. NLWs have had limited operational use. Commanding officers who have used them, for example, in Somalia and in an ongoing operation such as Kosovo, have become highly vocal advocates—along with some who needed them but did not have them at the time.
- *Experiments and training*. Experiments at the U.S. Marine Corps Warfighting Laboratory have matured the concept of operations (CONOPS) for many individual tactical uses of NLWs, and joint training curricula at the U.S. Army's Fort Leonard Wood, Missouri, have been established.
- *Continued widespread interest and discussion*. A continuum of high-level studies and conferences has reinforced—indeed expanded—the roles in which NLWs could contribute.
- *Navy interest*. The Marine Corps has been the leading Service proponent for NLWs throughout the past decade. When this study began, Navy interest in NLWs was difficult to identify, but the findings and recommendations of the Antiterrorism/Force Protection Task Force led by the Office of the Chief of Naval Operations (OPNAV) N34 are building a strong case for NLWs as an important element for protecting ships in port.

Despite these advances and in spite of the expressed wishes of many commanders in chief and Service leaders, the following troublesome issues could preclude NLWs from becoming an integral force option:

- *Lack of new ideas*. The combined factors of high visibility and small budgets appropriately focused the JNLWD at its inception on relatively mature technologies. The most promising have moved, or are nearing transition, to acquisition and are finding interesting but limited application. Little investment has been made in new ideas requiring further research, with the result that the JNLWD now has little in the pipeline ready for development investment.
- *Little Service investment in R&D*. The Marine Corps and Army, as the primary initial sources for reallocation of funds to the JNLWD at its inception, have drawn down their own investments in R&D. Air Force investments for explicit non-lethal weapons research have always been low, although promising directed-energy concepts, funded principally for their lethal potential, have found cofunding from the directorate and other agencies for specific non-lethal weapons applications. Navy interest and actions regarding NLWs in compliance with the 1997 memorandum of agreement (MOA) had been very limited until recently. As a result, the Service pipelines are "dry" as well.
- *Perceived treaty constraints*. The program for chemical antimateriel and antipersonnel NLWs, after many years of Army R&D investment and the identification of a number of promising technologies, was canceled with the adoption

of the Chemical Weapons Convention in the early 1990s. That program has not been started up again, in spite of legal interpretations of the treaty indicating that it does not preclude such work or the employment of such agents in specified and increasingly important military situations, such as civilian crowd control in peacekeeping or humanitarian relief operations.

• *Poor understanding of the effects and effectiveness of NLWs*. The effectiveness of NLWs is poorly understood in almost every dimension. While the process for assessing health and human effects has been established, as commended above, the funding levels and the overall philosophy leave much to be done in key areas, such as research into the fundamental biomechanical and physiological response mechanisms; translation of effects on individuals into effects on groups and/or effects associated with repeated exposure; development of effects models; and implementation of the models in experiments, testing, and wargaming environments. The parallel process for antimateriel NLWs, while somewhat easier to implement, is not formalized. Moreover, efforts to quantify military operational advantages and improvements in capabilities with NLWs, understanding of both U.S. vulnerabilities and enemy countermeasures to nonlethal weapons use, and development of a CONOPS have been very limited. In addition, the warfighter must understand and be able to adapt to the inherently variable effects of NLWs—as a specific engagement unfolds, it is essential that the warrior have the ability to obtain and act on immediate feedback to be able to "dial an effect" for re-engagement should that prove necessary. Well-characterized effects and effectiveness are probably the most convincing means of gaining widespread acceptance and integration of NLWs into warfighting capabilities, yet such characterization is currently the weakest aspect of the overall non-lethal weapons program.

• *Lack of systems concepts*. Given that the effectiveness of non-lethal weapons options is not well understood, it comes as no surprise that systems concepts and assessments are generally immature. Complete systems concepts, including delivery vehicles and sensors for targeting and effects assessment (i.e., the non-lethal equivalent of BDA), are few. Logistics and maintenance considerations are limited to ensuring compatibility with whatever exists. Fully integrated lethal and non-lethal weapons capabilities remain to be assessed, although such force mixes are essential to implementing effects-based targeting.

• *Overhead for entering the normal acquisition process*. The JNLWD funding is largely budget category 6.3, that is, funding allocated for exploratory development. The directorate's leadership has taken on the role of entering new concepts into the formal milestone acquisition process—which was designed to provide the scrutiny needed for large acquisitions but is ill-suited for the small levels of funding involved in JNLWD initiatives. Moreover, as a joint office, the directorate must work to find a Service partner for transition, a task that is made more difficult for the directorate because it is not part of the normal procurement planning cycle of any of the Services. On the other end, the "color" and total amount of JNLWD money make investment in research difficult. In short, following the normal Department of Defense (DOD) acquisition process does not serve the directorate, the Services, or DOD efficiently for a program that is so small and constrained yet is viewed as filling a much-needed role.

- *Organizational support within the Department of the Navy*. In contrast to the long-standing emphasis by the Marine Corps on expanding its non-lethal weapons capabilities, formal Navy interest, as evidenced by assessment, requirements, acquisition, or actions consistent with the 1997 MOA (see Box 1.1), has been practically nonexistent. Within OPNAV N757 only a single person has sole, and limited, responsibility for coordination of non-lethal weapons issues with the JNLWD. This approach has probably been adequate, given the focus to date on acquisition of individual warfighter tool kits, but it will not suffice as more complex and more capable non-lethal weapons systems (such as VMADS) mature. It will also not suffice for introducing NLWs as an integrated part of naval expeditionary force capabilities.

OVERALL CONCLUSIONS

Because of the range of effects introduced by NLWs, it is readily apparent that the issues associated with their development and use are more complex than issues associated with the development and use of their lethal counterparts. The committee agrees that, while progress since the establishment of the JNLWD has been laudable, important areas of concern remain. These concerns led the committee to the following conclusions:

- Without compelling new ideas, NLWs will remain a specialty item in the warfighter's tool kit and will never become the effective element of warfighting that countless studies and limited operational experience have affirmed NLWs can be.
- Without a different process for introducing new non-lethal weapons capabilities—one more integrated into each Service's normal development and acquisition cycle—the current scope of the program offers only a low probability of moving even the best ideas to the field in the future.
- Without a much stronger overall program to understand and characterize the effects and effectiveness of non-lethal weapons, commanders will remain reluctant to request or employ them.
- Without concepts for the use of non-lethal weapons, developers will not be successful in focusing ideas and programs.

In short, major changes in approach are needed to achieve the potential of NLWs for U.S. forces in general and naval forces in particular.

RECOMMENDATIONS

In developing its recommendations, the committee recognized that the terms of reference for the study had been written prior to the USS *Cole* incident, yet the study was conducted in the post-*Cole* environment in which a more urgent need for non-lethal options emerged for the Navy. Moreover, the critical gap in the technical understanding of non-lethal effects added to the committee's concerns that "business as usual" would not allow important S&T ideas to make the transition to acquisition and deployment in a reasonable timeframe. The terms of reference directed the committee to review the JNLWD program of record. In doing so, the committee concluded that organizational as well as technical recommendations were required. While no formal analysis of organizational alternatives was made, the committee did consider and reject the extreme alternatives of the JNLWD being shut down and that of the JNLWD continuing on as it is, and accepted instead the alternative that the JNLWD needs to change its present focus.

The committee's recommendations are made in order that any S&T investment on the part of ONR will have a reasonable probability of successful transition to the warfighter. The recommendations identify a pragmatic approach (i.e., mindful of resource constraints), principally through significant shifts in the emphasis of the currently available resources to the JNLWD and the assumption of research, development, and acquisition (RDA) responsibilities by the Navy and Marine Corps. This section provides an overview of the committee's recommendations. Chapter 5 presents detailed recommendations for their implementation.

Joint Non-Lethal Weapons Directorate: As the Department of Defense's focal point for non-lethal weapons, the Joint Non-Lethal Weapons Directorate should focus its resources on stimulating and exploring new ideas, and on strengthening the DOD's ability to characterize the effects and effectiveness of non-lethal weapons.

At this juncture in the maturing of the JNLWD, the committee recommends that the directorate declare success in its initial phase of meeting the demand for quickly fielded capabilities and, for the future, move to a new and more robust role that is much better aligned with its joint status. This next phase for the JNLWD should focus on two principal roles: (1) advocacy backed by funding and expertise to support joint experimentation, systems modeling and analysis, functional concept exploration programs, and advanced concept technology demonstrations (ACTDs), along with stimulating new ideas from the S&T community while the Services build up their own programs; and (2) establishing, maturing, and overseeing multiple centers of excellence (COEs) for the study of human and materiel effects. With the COEs to support it, the directorate should be assigned the role of independent assessor of any new non-lethal weapons concept, to affirm that effects are properly characterized and understood. This refocusing of the directorate away from non-lethal weapons development and toward a transition to acquisition roles would allow it to address the critical limiting factor for widespread integration of NLWs: namely, the lack of a clear understanding of the effects and effectiveness of NLWs.

In parallel with the refocusing of the JNLWD's roles, the Services must assume their full range of responsibilities for the research, development, and acquisition of non-lethal weapons systems to meet their own specific needs instead of continuing with the current process whereby the directorate awkwardly picks up interim steps at the 6.3 budget stage. Given that the Marine Corps has both the most mature understanding of and experience with NLWs, and that the Navy is motivated by needed improvements in port protection and expanded strike capabilities, ONR should have ample justification to invest in non-lethal weapons R&D as a part of an overall transition within the Department of the Navy toward assuming end-to-end responsibilities for non-lethal weapons development, acquisition, and deployment.

Implementing these changes in roles and responsibilities across the JNLWD and the Services will require a revision to the Joint Service Memorandum of Agreement on Non-Lethal Weapons. The Office of the Secretary of Defense, the Joint Chiefs of Staff, and the Services, in addition to the JNLWD, will have to agree to the changes proposed above. Moreover, the Services' assumption of end-to-end development and acquisition responsibilities will require the commitment of their own resources (funding and personnel) to establish their in-house programs.

Centers of excellence: The Joint Non-Lethal Weapons Directorate should establish and sustain human and materiel effects-focused centers of excellence to support a "seal of approval" process for non-lethal weapons systems.

The program dimension involving COEs should remain with the JNLWD, as noted above. It is emphasized here, regardless of the future direction and focus of the directorate, because the human effects issue is critical for expanded NLW use. The scope of the COEs should be comprehensive and should include responsibilities for the following:

- Developing and implementing a focused research agenda to advance the state of fundamental understanding;
- Creating and sustaining effects databases, and identifying shortfalls in the knowledge base;
- Prioritizing and executing research to fill knowledge gaps;
- Developing, validating, and integrating effects models;
- Serving as a consultant to the development community to define test regimes and protocols for developmental systems and transition to acquisition; and
- Providing expertise to support JNLWD independent assessment function.

The directorate has recognized the utility of the COE approach with the establishment of the Human Effects Center of Excellence at Brooks Air Force Base, San Antonio, Texas. Additional COEs are needed, however, because of the unique expertise required to understand each of the effects associated with the wide variety of NLWs (e.g., blunt trauma with kinetic energy non-lethal weapons, penetration of skin and effects on the retina of the eye with millimeter and microwave radiation, chemical effects of calmatives and malodorants, effects of antimateriel NLWs, and so on). Research within or supported by each COE should encompass the determination of thresholds for permanent damage or injury. The committee estimates that about five or six COEs would be needed, each focused on a particular class of NLW, examples of which are noted above. Each COE should be funded initially by the JNLWD at a sustaining "foundation" level of a minimum of $1.5 million per year to support the critical mass of expertise required to maintain the knowledge base, set the research agenda, and model fundamental effects. Service funding and cooperative funding should be developed at this initial stage.

Funding for the research agenda is not included in this foundation level, nor is funding to accomplish the integration and accreditation of models needed to support the seal of approval process. The JNLWD must develop a prioritized research agenda that integrates the agendas from the individual COEs, and it must then augment COE funding to support research priorities. After the initial stage, Service funding should bear the majority of the COE funding; however, the JNLWD should also augment COE funding to support integration and accreditation of effects models, with DOD program managers funding system-specific models and tests.

Science and technology: In cooperation with the JNLWD and the other Services, ONR should invest in a richer portfolio of NLW-specific R&D activities in the areas of chemicals; directed energy; barriers and entanglements; underwater defensive systems; and platform, sensor, and command and control system enablers.

Areas for ONR emphasis include HPM research and development as planned by the Naval Research Laboratory, barrier and entanglement deployment systems for stopping vessels, accelerated research on solid-state lasers for operational non-lethal weapons applications, weaponization of antimateriel chemical NLWs for use in stopping engines and as antipersonnel calmatives, and use of unmanned aerial vehicles, unmanned ground vehicles, and unmanned underwater vehicles as delivery platforms. In the chemicals area, the committee recommends a strong partnership with the Army's Edgewood Chemical and Biological Command, which has expertise in and a history of screening chemicals for such applications. ONR should also support platform and sensor development to address the Navy's unique needs for remote deployment and effects assessment of non-lethal weapons technologies, for example in port underwater, surface, and air defense non-lethal weapons systems. Particularly stressing is the time line for the BDA equivalent function of effects assessment with non-lethal weapons systems, which places more stringent requirements on the sensor system(s) associated with their use.

A second specific recommendation concerns the VMADS, recently demonstrated as a potentially effective antipersonnel NLW and envisioned for mounting on a ground vehicle. Suggestions have been made within the Navy about its deployment shipboard for port protection, but the idea should be fully assessed within the Department of the Navy to establish the cost-effectiveness of such a system before development resources are committed. A final recommendation related to S&T is made to the JNLWD, which is currently supporting two chemical laser programs, the advanced tactical laser (ATL) and the pulsed-energy projectile (PEP). The evidence presented to the committee supporting claims of the viability of both these concepts for non-lethal weapons use was not convincing. The directorate is urged to reassess its investments in these programs.

Department of the Navy: The Secretary of the Navy, the Chief of Naval Operations, and the Commandant of the Marine Corps should establish a senior-level working group to actively oversee the integration of non-lethal weapons into naval warfighting requirements, research and development programs, acquisition plans, and operations.

Non-lethal weapons represent a new capability that must compete in a resource-constrained environment with traditional capabilities that already have well-established requirements and proponents. Without the attention of senior leadership for some period of time, integration of NLWs into the naval forces will most likely proceed at a glacial pace—or may never happen. The broad range of non-lethal weapons applications compounds the problem in that there are many potential candidates (and corresponding proponents) for maturation rather than a single logical one, so that in the end, no one "owns" (i.e., is responsible for) the requirements and development process for the area.

The committee believes it is imperative that senior officials and officers within the Department of the Navy, acting on behalf of naval force (i.e., Navy and Marine Corps) requirements, become knowledgeable about and take responsibility for the development and integration of non-lethal weapons systems into naval mission readiness. The recommended mechanism is a working group chartered to develop a naval non-lethal weapons master plan for naval expeditionary forces. Such a plan should establish mechanisms to ensure that non-lethal weapons will become fully integrated into, and can compete fairly in, the requirement and development process for all naval systems.

1

Introduction

1.1 NON-LETHAL WEAPONS: DEFINITION AND EVOLVING RATIONALE

Definition

Non-lethal weapons (NLWs) are defined by the Department of Defense (DOD) as "weapons 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."[1]

Evolving Rationale

General Considerations

Non-lethal weapons technologies may augment, enhance, complement, and/or substitute for political processes in the resolution of conflict. In certain situations, they may act as a force multiplier. There is no single "silver bullet" non-lethal weapons technology because of the range of applications and environments for the use of NLWs. Candidates for employment must be available, affordable, reliable, and simple to use, and must minimize casualties among friends, foes, or

[1]Department of Defense. 1996. *Directive Subject: Policy for Non-Lethal Weapons,* DODD 3000.3, Washington, D.C., July 9, p. 2.

neutrals. Their use may lead to decisive action, such as the control of an area, while limiting collateral damage and the need for reconstruction.

NLWs have appealing attributes for warfighters in current environments of peacekeeping support, regional conflict, and asymmetric threat. They create an option for controlled action, and may even keep lethal force from being the sole means of solving a crisis when diplomatic, economic, and sanction-based approaches have failed. They can reinforce deterrence and credibility by providing a commander with a graduated response over a wide range of military activities. NLWs may also allow early, non-precipitous response to a conflict by providing a progressive, incremental, and measured response without lethal consequences.

NLWs have utility across the spectrum of conflict and at all levels of command. In some instances, their use may be publicly and politically attractive; it can buy time, with few or no casualties while diplomatic solutions are sought. When employed at operational and strategic levels, the use of NLWs can reduce the cost of rebuilding infrastructure and economies.

Growing Support

Since the end of the Cold War, the United States and its allies have been increasingly involved in operations other than war (OOTW), including peacekeeping, peace support, and humanitarian operations. The use-of-force constraints placed on U.S. forces through the rules of engagement (ROE) have often required that any collateral casualties be held to a minimum.

In 1995 the Council on Foreign Relations (CFR) published the results of a study on NLWs and concluded that they would be valuable in future conflicts.[2] The National Defense Authorization Act of 1996[3] required consolidation of non-lethal weapons responsibilities. Deputy Secretary of Defense John Deutch responded by directing DOD to become actively involved in planning for integration of non-lethal weapons; this led to the formation of the Joint Non-Lethal Weapons Directorate (JNLWD) in May 1996. However, funding sources were not established until December of that year, and the first year of separately budgeted funds for the JNLWD was FY98, with $16.6 million in reprogrammed funds from the U.S. Army and the U.S. Navy. In January 1997, a Joint Service

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[2]Weiner, Malcolm H. 1995. *Report of an Independent Task Force on Non-Lethal Technologies: Military Options and Implications,* Council on Foreign Relations, New York.

[3]Congress provided direction to DOD via the National Defense Authorization Act of 1996 (P.L. 104-106), in which it stated, "SECDEF shall assign centralized responsibility for development and [any other functional responsibility the Secretary considers appropriate] on non-lethal weapons technology." On February 14, 1996, the Office of the Secretary of Defense published a memorandum stating, "We need to . . . (1) get a good understanding of the Department's NLW activities . . . (2) develop an NLW management approach for the Department, and (3) . . . decide on a level of expenditure in this area."

Box 1.1
Joint Service Memorandum of Agreement on Non-Lethal Weapons

On January 21, 1997, a memorandum of agreement (MOA) on the DOD non-lethal weapons program was signed by the Chief of Staff of the Army, the Commandant of the Marine Corps, the Chief of Naval Operations, the Chief of Staff of the Air Force, and the Commander in Chief of the U.S. Special Operations Command. This MOA was superseded by the current agreement, dated June 23, 1999. The agreement directs the Services to develop and recommend to the Office of the Under Secretary of Defense for Acquisition and Technology a fully integrated and coordinated non-lethal weapons program to include, as appropriate, classified non-lethal weapons programs within DOD that meet the intent of Congress and provide the best non-lethal weapons technologies and equipment to support U.S. operating forces. Section 3.6 of the MOA states:

> The Services will have the responsibility for:
>
> 3.6.1. Developing Service-unique NLW operational requirements and system characteristics;
> 3.6.2. Submitting NLW operational requirements for review for joint applicability;
> 3.6.3. Identifying requirements for NLW specific logistics;
> 3.6.4. Conducting research, development, test and evaluation when designated the lead-Service for acquisition in accordance with references (3) and (4);[1]
> 3.6.5. In coordination with the lead-Service, developing Service-unique NLW doctrine, training, and logistics requirements and testing standards;
> 3.6.6. Presenting Service-unique NLW programs to the Joint NLW Director for information purposes;
> 3.6.7. Providing membership to the IPT [integrated product team] and JCIG [joint coordination and integration group] as set forth herein;
> 3.6.8. Managing allocated funding for assigned lead-Service NLW projects;
> 3.6.9. Submitting and coordinating inputs into Service program objective memorandums (POMs) for Service-unique NLW research, development, testing, and evaluation (RDT&E) and procurement.

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[1]Reference 3: Department of Defense. 1996. DOD Directive 5001, "Defense Acquisition," Washington, D.C., March 15. Reference 4: Department of Defense. 1996. DOD Directive 5000.2-R, "Mandatory Procedures for Major Defense Acquisition Programs (MDAPs) and Major Automated Information Systems (MAIS) Acquisition Program," Washington, D.C., March 15.

Memorandum of Agreement for support of the JNLWD was signed; it was updated in 1999 (see Box 1.1).

DOD created the JNLWD under the executive agency of the U.S. Marine Corps. Despite its relatively low funding, the JNLWD was highly visible to both Congress and DOD, and it was under pressure to focus on acquiring available technology that could be fielded as quickly as possible—especially to provide NLWs to troops already located in the Balkans and on other peace support operations. The directorate has been successful in fielding selected NLWs and kits of NLWs but now faces the need to develop more advanced and robust capabilities.

Hard lessons were learned about the value and limitations of NLWs in Somalia, Haiti, Rwanda, Bosnia, Macedonia, and other places to which U.S. troops had been sent and where combatants and non-combatants mixed in close proximity. Senior commanders who deployed on these missions became vocal proponents of NLWs. LtGen Anthony C. Zinni, USMC (now Gen (retired)), Commander of United Shield, the exfiltration of United Nations forces from Somalia, asked for and received a quick response to his request for fielding of NLWs. Though of limited capability, the NLWs that were used received credit from General Zinni for contributing to the successful completion of the mission. He also noted that he "would never go on another peace support mission without them."[4] Similarly, Gen John Sheehan, USMC (retired), former Commander in Chief, U.S. Atlantic Command, became a strong advocate of NLWs when he sent troops to Haiti in Operation Uphold Democracy. Later, when speaking at the Non-Lethal Defense Conference II, he emphasized the necessity of those weapons becoming standard military issue.[5]

Expanding Roles for NLWs

Non-lethal weapons capability has been viewed historically as an element of military operations other than war (MOOTW)—most especially, for peace support operations. In a recent study,[6] however, the JNLWD concluded that NLWs can contribute in the full spectrum of conflict—ranging from major theater wars (MTWs), to small-scale contingencies (SSCs), to peacetime operations, and homeland defense. More importantly, these assertions were also noted in the FY01 defense planning guidance:

> NLWs have proven useful across the range of operations, including both conventional combat operations and the many categories of military operations other than war. . . . Current efforts to study and understand the use of NLWs from the strategic to the tactical levels must be integrated into all future military and interagency concepts and operations.[7]

Today non-lethal weapons capabilities are being considered for a variety of missions, such as humanitarian relief, peacekeeping, law enforcement, military operations in urban terrain (MOUT), truce monitoring, counterterrorism, drug interdiction, disaster response, and force protection.

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[4]Lawson, Chris. 1995. "Zinni: Missions Allow MEUs to Shine," *Army Times,* Volume 55, No. 39, p. 23.

[5]Sheehan, Gen John, USMC (Ret.) speaking at the Non-Lethal Defense Conference II, Washington, D.C., March 7, 1996.

[6]American Systems Corporation. 1999. *Joint Vision for Non-Lethals: Meeting the Demand of Future Military Operations,* ASC, Dumfries, Va., December.

[7]Department of Defense. 2001. *Defense Planning Guidance,* Washington, D.C.

1.2 ROLES OF NON-LETHAL WEAPONS FOR NAVAL EXPEDITIONARY FORCES

U.S. Navy Needs for NLWs

A spectrum of missions, both defensive and offensive, that are unique to the Navy can employ NLWs. The defensive missions include force protection—particularly for vessels with heightened vulnerabilities, such as those in port, those transiting straits and other choke points, and those in military supply convoys. The offensive missions include ship interdiction, blockades, and strikes. The next two subsections elaborate on these mission areas.

Defensive Mission Needs

Force Protection

For force and vessel protection, the Navy should have non-lethal weapons that function in all three non-lethal capacities: counterpersonnel, countermateriel, and countercapability. These include means for crowd control, individual incapacitation, area and access denial, clearing of areas, stopping and disabling of vehicles and vessels, and protection against asymmetrical threats such as dispersal of chemical or biological agents. Protection of personnel and ships at anchor or in port, both pierside and outboard, is essential. A strategy emerging since the USS *Cole* incident in October 2000 is the enforcement of a layered defense with three zones around the perimeter of a vessel.[8] The outer zone is designed to alert personnel and to warn an incoming platform or individual; the middle zone is intended for assessing or affirming intent if the incoming platform or individual has not somehow acknowledged the warning given in the outer zone; the inner zone is focused on engaging the threat. Non-lethal options are desirable in such situations because assessed threats may involve unintended intrusion or non-combatants, and time lines for response may be too compressed to establish intent unambiguously or to isolate the threat from innocent people. (A more detailed discussion of the layered architecture is presented in Appendix A.)

The layered strategy requires the ability to determine the presence and extent of potential threats on the surface, under water, and in the air—and then to deal rapidly with them through a complement of responses. While surface threats have been the focus historically, underwater and airborne threats appear to be growing as a result of advances in and increasing access to diving equipment, small submarines, and unmanned undersea and airborne vehicles.

[8]Arminio, CAPT Thomas, USN, "SECNAV AT/FP Task Force," briefing to the committee on March 7, 2001, Office of the Chief of Naval Operations, N3/N5B2, Washington, D.C.

Establishing zones around the perimeter of a ship requires delineating the zones with barriers that have visible markings and warning devices, such as flashing lights and lasers, or with "smart" buoys with day/night/all-weather sensors and sound emitters. Once the outer barrier is penetrated, assessment of intent and tactics to delay or deter the threat are required. If a potential threat crosses into the middle zone, the option is open for delivering a warning with a non-lethal deterrent such as "flash bangs" or electronic vessel stoppers. Entry into the inner zone requires the use of tools that engage the threat directly through either lethal or non-lethal means. The options selected must be effective on a time scale that allows the employment of lethal means if the NLW fails to deter the threat. Increasing situational awareness both aboard ship and at nearby shore and harbor facilities through the use of increasingly sophisticated surveillance assets, such as imaging sensors on unmanned aerial vehicles (UAVs) or remotely piloted surface craft, and/or underwater sensors, will not only contribute to understanding intent, but it will also maximize the time available for response.

This layered strategy is challenging to implement, given both the physical and political realities of today's world. U.S. ships in foreign ports are in close proximity to other vessels of all sizes. Armed patrol boats may not be acceptable to host nations. Enforcing specified zones of protection for U.S. ships in international harbors must rely on diplomatic negotiation, not just on the technological ability to distinguish a legitimate threat from many benign activities. Having non-lethal weapons options available could support such negotiations.

Other Defensive Needs

While the need for protection of ships in port is an all-too-familiar example following the attack on the USS *Cole,* other types of defensive mission needs can also be facilitated by NLWs. Ships passing through choke points or operating in the littorals are vulnerable to attack from hostile crowds on shore, to suicide vessels, and to terrorists on land, in the water, or in the air. Military supply convoys have limited weapons onboard. Base security requires capabilities for crowd control, individual incapacitation, area and access denial, and the ability to clear facilities. In all of these diverse environments, threats can be ambiguous and involvement of noncombatants possible.

Offensive Mission Needs

Sea Strike Concept

The previous Chief of Naval Operations (CNO), Admiral Jay L. Johnson, USN, expressed his vision for the Navy in a paper entitled "Anytime, Anywhere:

A Navy for the 21st Century,"[9] in which he envisions a Navy, with its sister Services, that "can and will shape the strategic environment and have a decisive impact from the sea on the crises and conflicts of the future; that [the Navy] can and will fight [its] way through any opposition at sea or in the air; and that [it] can project and sustain enough power ashore—carrier air, gunfire, missiles, and Marines—to deter a conflict, to stop an aggressor, or to pave the way for heavier joint forces." The CNO's vision paper summed up his outlook in one succinct sentence: "The purpose of the U.S. Navy is to influence, directly and decisively, events ashore from the sea—anytime, anywhere." The CNO clearly envisioned the future operating environment of naval forces to be increasingly characterized by continuous combined arms operations designed to dominate a battlespace and bring about the rapid defeat of an enemy.

In October 1998, the Strategic Studies Group (SSG) XVIII examined the nature of future opponents and the Navy's future capabilities for detecting, identifying, and rapidly targeting all types of land targets. SSG XVIII developed the revolutionary operational concept named "Sea Strike—Attacking Land Targets from the Sea."[10] The concept combines high-volume striking power from naval aircraft, missiles, and guns with maneuver forces, very high rates of fire, and fully networked sensors, all designed to maneuver directly and decisively ashore to shock, destroy, and rapidly defeat the enemy. A critical aspect of the concept is that the commander has available the "full-spectrum effects" enabled by "effects-based weaponeering." As described by SSG XVIII:

- *Full-spectrum effects* allow the commander to accomplish any mission while complying with a dynamic range of rules of engagement. The commander is not faced with choosing between doing nothing and taking action that would involve unacceptable collateral damage. It is imperative that the commander has a wide variety of tools and methods that can be tailored to the operational situation, thereby enabling a full spectrum of effects.
- *Effects-based weaponeering* is the process of rapidly pairing affordable, precise weapons with each target to achieve exactly the desired effect. An automated manual on future joint munitions effectiveness would be created to address the following: coordinated weapons and non-weapons effects such as command and control warfare; complementary lethal and non-lethal munitions; integrated landing force, coalition, and supporting joint weapons; and damage preclusion guidance for the commander. This broader approach to weaponeering allows the commander to combine all forms of military and non-military power into an integrated package.

[9]Johnson, ADM Jay L., USN, Chief of Naval Operations. 1997. "Anytime, Anywhere: A Navy for the 21st Century," *Proceedings,* Volume 123/11/1,137, U.S. Naval Institute, Annapolis, Md., November, pp. 48-50.

[10]Bill Glenny, Deputy Director, CNO Strategic Studies Group XVIII, private communication, November 8, 2001.

Sea Strike in a Major Theater of War

During all five phases of a strike campaign—(1) close and shape, (2) halt the attack, (3) prepare the battlespace, (4) support maneuver forces ashore, and (5) transition to the postconflict phase—non-lethal weapons provide capabilities for counterpersonnel, materiel, and functional nodes. Specifically, they would enable the commander to accomplish the following:

- Control crowds, incapacitating individuals and/or groups;
- Deny access to areas by personnel, vehicles, vessels, and aircraft;
- Clear facilities, structures, and areas;
- Disable or neutralize facilities, vehicles, vessels, aircraft, and equipment; and
- Deny or disrupt the use of weapons of mass destruction (WMDs).

Given the inherent capabilities of the Sea Strike land attack concept, operational NLWs offer the potential for enhancing the effectiveness of lethal forces by, for example, enabling the commander to engage early, immobilizing enemy equipment without permanent damage to roads or bridges, and turning moving targets into stationary targets. Non-lethal capabilities can also establish areas of denial and restrict an adversary's sea space and air space. Non-lethal means can deny an enemy the use of equipment and facilities. For instance, non-lethal directed-energy weapons can disrupt enemy air defenses and early warning detection sensors; they can also neutralize minefields. Non-lethal payloads can neutralize chemical and/or biological weapons and destroy or disable supporting infrastructure, such as command and control, communications, and navigation systems.

Sea Strike to Support MOUT and MOOTW

In preparation for attack on an urban target, the commander must assess the value of engaging the target in light of the rules of engagement for collateral damage and non-combatants. Engagement of urban targets requires a variety of weapons and methods. A common challenge of urban combat is the mixing of non-combatants with military targets, either accidentally or intentionally. Operational NLWs can help simplify this situation by enabling the commander to perform the functions listed above.

SSG XVIII summarized that allocating adequate resources to the development of NLWs may ensure that future commanders are capable of utilizing the concept to deliver optimal effects on specific targets across the full spectrum of conflict.

Maritime Interdiction

Maritime interdiction is carried out by the U.S. Navy for a variety of reasons, such as enforcement of UN sanctions (e.g., in the Persian Gulf) and enforcement of U.S. treaties. It is a mission area made broader by virtue of the fact that the U.S. Coast Guard often uses Navy assets when carrying out its own law enforcement responsibilities, particularly drug interdiction and fisheries enforcement. Ship interdiction requires the ability to detect, as well as to delay, stop, or temporarily disable, vessels of various types, sizes, and speeds. Ramming or collision is a high-risk action and is usually unacceptable. Intercepted vessels must be boarded, usually in difficult conditions, and this requires the means to subdue potentially hostile individuals or entire crews at close range in confined areas. All aspects of such a mission would be significantly enhanced with the availability of non-lethal weapons options.

Blockade

Needs similar to those in maritime interdiction can arise from the Navy's blockade mission (and its peacetime equivalent of quarantine): that is, denying an adversary's use of the seas involves preventing resupply and reinforcements or keeping an adversary's vessels in port. Non-lethal weapons options are required to delay and stop vessels, including large ships in deep waters, and to apprehend crew members and their cargoes while minimizing risk to U.S. personnel.

U.S. Marine Corps Needs for NLWs

The U.S. Marine Corps has operational non-lethal weapons capabilities today. The Marines expressed their requirements in 1996 through the formal mission needs statement (MNS) process in order to support military operations other than war. As a result, they deploy a basic capability set of NLWs that includes counterpersonnel and countermateriel core capabilities for use at the tactical level by individual Marines. These capabilities are designed to control, stun, incapacitate, or hinder the movement of individuals or crowds; to disable without destroying equipment; and to augment the protective equipment that the individual Marine carries or wears in the field.

The U.S. Marine Corps has modified its previously held view that non-lethal weapons capabilities are applicable primarily to MOOTW. In fact, Marine Corps plans now include NLWs as essential capabilities for military operations in urban terrain. MOUT involves joint combat across the full spectrum of conflict and is often conducted in a complex environment where intent is ambiguous and combatants and non-combatants operate in close proximity. That situation requires non-combatant personnel and materiel protection (often necessitating that non-combatants be recognized as such and then be separated from combatants) as well as the preservation of many structures. To deal with the complexity of such environments, commanders need more options that can include non-lethal weapons capabilities.

The Marine Corps is leading efforts to develop two operational requirements documents (ORDs)—one for clearing facilities and the other for incapacitating personnel. At the same time, through two concept exploration programs (CEPs), it is determining which non-lethal weapons technologies can be effective at close and standoff ranges. The first CEP is focused on augmenting surveillance and sensing capabilities that can be used at standoff ranges, clearing compartments and rooms by causing occupants to leave, and providing the means to deny access to a cleared area, for example, by inhibiting mobility. The second CEP is investigating non-lethal weapons technologies such as kinetic energy, directed energy, or sensory overload systems for controlling individuals or groups through temporary disablement, distraction, or disorientation.

1.3 DESIRABLE CHARACTERISTICS OF NON-LETHAL WEAPONS FOR NAVAL EXPEDITIONARY FORCES

Coupling the general background and rationale for NLWs with naval war-fighting considerations as presented in the previous two sections, the committee agreed on the set of characteristics and generic missions listed in Boxes 1.2 and 1.3. The items in Box 1.2 are the criteria against which technologies recommended for further development were screened by the committee.

The mission list in Box 1.3 is not presented in any priority. However, the technical characteristics listed in Box 1.2 are ordered in two groups: the first characteristic, effects on target, takes priority over all the others as the essential criterion for any NLW. NLWs must provide enhanced operations for the military commander. This implies technologies that are reliable and cost-effective and that provide significant effects at standoff ranges sufficient to allow a transition to greater force if necessary. Effects demonstrated as repeatable and significant when used in a specific scenario are key. Commanders will be reluctant to employ NLWs if there is uncertainty about the effects of their use or if the lack of a consistent effect exposes sailors or Marines to additional risk. This criterion is more significant in context: by their nature, non-lethal weapons technologies often exhibit a wider range of effects and less clear-cut effectiveness when compared with lethal counterparts.

Once acceptable effects on target are established, then the other characteristics listed in Box 1.2 come into play. Other technical characteristics are not unlike those for lethal weapons, but because NLWs are to be employed as an added capability—not as a replacement—these characteristics have to be more rigorously considered. For example, commanders will not support deployment of NLWs if it means replacing a significant fraction of their lethal capability to accommodate the logistical burden of NLWs. In fact, the ideal NLW would have a "dial-an-effect" capability that could push it into the lethal range as the situation demanded. NLWs should also integrate seamlessly into existing force structures in terms of organization and training.

Box 1.2
Technical Characteristics of Non-Lethal Weapons

1. Effects on target (significant, repeatable effects)
2. Rheostatic capability
3. Selective targeting
4. Portable by a person or existing vehicle
5. Standoff/range
6. Ease of cleanup
7. Developmental maturity
8. Complementary or synergistic technology
9. Acquisition and operational costs (training, maintenance, reuse, and so on)
10. Robustness to countermeasures

Box 1.3
Selected Mission Applications for Naval Expeditionary Forces

1. Ship perimenter protection
2. Small boat disablement
3. Temporary ship disablement
4. Land vehicle disablement
5. Securing and clearing of facilities
6. Swimmer detection and control
7. U.S. Coast Guard "fast boat" interception
8. Pierside force protection
9. Area denial
10. Crowd control
11. Incapacitation of individuals

Currently employed NLWs are typically used from close contact out to tens of meters from potential adversaries. There is a common requirement across many of the non-lethal mission areas to extend the range of NLWs to hundreds of meters or kilometers. Non-lethal weapons technologies should be adaptable across a range of military operations and should provide significant benefit in a variety of non-lethal application scenarios. "Expeditionary" implies rapid response, mobility, endurance, and sustainability in austere environments.[11] Weight and volume are significant constraints for both airlift and shipboard deployment of naval expeditionary forces. The expeditionary environment generally requires that any weapon system be highly mobile and portable by individual troops or existing vehicles.

[11]Director, Joint Non-Lethal Weapons Directorate. 1998. *Joint Concept for Non-Lethal Weapons,* Quantico, Va.

2

The Current Status of Non-Lethal Weapons

In assessing the full spectrum of effort and attention given to non-lethal weapons, the committee found the area to be broad but with significant interrelationships. To place in context the findings and recommendations presented in subsequent chapters, this chapter summarizes (1) the current status of non-lethal weapons technologies and effects on the health of personnel against whom the NLWs are used; (2) the progress of the Joint Non-Lethal Weapons Directorate, the focus of DOD's joint activity in NLWs; and (3) the activities in other areas that influence the understanding and use of these weapons, including Service and other agency development programs and operational experience, science and technology status, recent studies and assessments, and the legal environment within which the use of NLWs must be addressed.

2.1 NON-LETHAL WEAPONS TECHNOLOGIES

There are numerous, very broad classes of technologies that have been considered for non-lethal use. Several previous studies[1,2,3,4] have exhaustively cataloged potential technologies, systems, and mission areas. Different taxonomies, data-

[1]Jaycor. 1996. *Mission Applications of Non-Lethal Weapons*, San Diego, Calif., July 9.

[2]Jaycor. 1994. *Non-Lethal Technologies Database for OASD-SO/LIC*, San Diego, Calif., June 21.

[3]Air Force Scientific Advisory Board. 2000. *Report on Technology Options to Leverage Aerospace Power in Operations Other Than War,* SAB-TR-99-11, Department of the Air Force, Washington, D.C., February. Available online at <http://www.sab.hq.af.mil/archives/reports/index.htm>.

[4]Sauer , Maj Joel, USMC, "U.S. Marine Corps Non-Lethal Weapons Experimentation," briefing to the committee on March 6, 2001, Marine Corps Warfighting Laboratory, Quantico, Va.

bases, and mission analyses have been completed as part of these studies. One of the most recent studies was the Joint Mission Area Analysis (JMAA) Conference sponsored by the JNLWD.[5] This was a joint-Service evaluation that broadly reviewed potential non-lethal weapons technologies. Technologies were sorted by potential for application in more than 100 mission areas and by their perceived adaptability to different delivery modes. Of 45 potential technologies reviewed, the study identified 12 candidate technologies for development: (1) millimeter wave, (2) chemical oxygen iodine laser (COIL), (3) antitraction materials, (4) non-lethal delivery and deployment, (5) malodorants, (6) calmatives, (7) high-power microwave (HPM), (8) rigid foams, (9) tagging and tracking, (10) nanoparticles, (11) laser scattering obscuration, and (12) deuterium-fluoride/hydrogen-fluoride (DF/HF) lasers.

The JMAA Conference and the studies cited provided the basis for the technologies considered in this study. The extensive list generated appears in Table B.1 in Appendix B. The non-lethal-weapons technologies are grouped in six categories: (1) kinetic-energy technologies, (2) chemical and materials technologies, (3) directed-energy technologies, (4) acoustic technologies, (5) electrical technologies, and (6) barriers and entanglements.

Kinetic-energy NLWs include devices such as rubber bullets and stun grenades. Examples of chemical NLWs include malodorants and pepper spray for use against individuals, as well as fuel contaminants for disabling vehicles. Directed-energy non-lethal weapons systems include radio frequency (RF) transmitters for disrupting vehicle engines, as well as the familiar laser dazzler for use against individuals. Examples of acoustic non-lethal weapons systems are intense sirens and whistles for area denial. Electrical NLWs include tasers (stun guns) to incapacitate individuals. Finally, barrier non-lethal weapons technologies include entanglement systems for stopping vehicles and sticky foams for use against individuals. Each category is discussed below in greater detail.

Two additional technology areas not specifically included in the six categories described above are essential to the success of NLWs; they are discussed as well. The two areas—referred to as enabling technologies—are delivery systems and sensor systems. Many NLWs, in order to be effective while remaining safe, require accurate delivery at long ranges. In addition, delivery systems with the flexibility to handle a variety of NLW payloads are desirable. Similarly, advanced sensor systems are required to identify potential targets, to ensure accurate delivery of NLWs, and to assess their effects.

Kinetic-Energy Technologies

Most non-lethal kinetic-energy weapons derive from their lethal counterparts. The rubber bullet for crowd dispersal is the classic example. Other kinetic

[5]U.S. Special Operations Command. 2000. Joint Mission Area Analysis Conference, October 17-20.

energy NLWs are concepts combined with other non-lethal techniques, such as non-lethal mines delivering smoke, electric shock, or pepper spray for area denial, and grenades for delivering anti-riot gas. Kinetic-energy NLWs were among the first non-lethal weapons developed, and they have been used extensively by police, troops, and security forces. Most non-lethal rounds and grenades are designed to be fired from existing weapons. The short range of many of these munitions, together with their deteriorating accuracy at range, limits their use to situations involving short standoff distances. For the most part, these weapons are well developed. Nevertheless, improvements are being pursued to broaden their applicability, extend their reach, and ensure their non-lethality.

Table B.1 in Appendix B identifies many kinetic-energy-based NLWs. Non-lethal projectiles of various kinds have been developed to stun, confuse, and disperse individuals and crowds. Rubber projectiles can be fired from standard-issue 12-gauge shotguns, either singly or in clusters of 12 balls, with a range of up to about 30 meters (m). The 40-millimeter (mm) Mk19 grenade developed for shooting from M203 and M79 weapons dispenses rubber balls for dispersing large crowds and achieving site security. The 40-mm sponge grenade can knock down an individual at 50 m. The ring airfoil grenade launched by an M234 is an aerodynamically shaped, soft rubberlike ring that spins in flight and is accurate from 40 to 60 m. Stun guns in the form of air/water jets mounted on vehicles are designed for crowd control. For intercepting speeding boats, developmental work has been carried out on a 6.25-in.-diameter non-lethal torpedo capable of carrying a 50-lb payload.

Control of trauma level from blunt projectiles remains a serious problem. At sufficiently close range, a rubber bullet can be lethal. Some effort has gone into designing a rifle system having an adjustable projectile muzzle velocity depending on distance to the target (and possibly, seriousness of threat), thereby allowing control of blunt trauma effects. The British and Israelis have extensive experience in using kinetic-energy non-lethal weapons for crowd control and dispersal. Through improved technology, the British, in particular, have been highly successful in limiting fatalities resulting from blunt projectiles. (See Section 2.7.)

Knowledge of the level of blunt trauma from a given non-lethal weapon system is almost entirely empirical, gained largely from experience in the field and from limited tests on animals. The effects on a human can be highly variable, depending on factors such as target distance, strike location, and individual human characteristics. At the present time, there exists neither a database nor calibrated models of the response of skin, tissue, and organs to blunt impact from which to assess human effects of non-lethal kinetic-energy weapons. The absence of such data and models impedes development of new non-lethal weapons systems and makes it difficult to establish envelopes of safe use for existing systems. Although knowledge accumulated in research on blunt trauma in the automotive industry is useful, new knowledge is required regarding the human effects of kinetic-energy weapons, because the speeds are higher and the mass of the projectiles is lower in comparison with automotive crashes. Research on sports injuries is another area to be investigated for relevant effects data.

Chemical and Materials Technologies

A large array of chemicals and materials have been suggested as candidates for use as NLWs. They fall into two broad categories: (1) antipersonnel and (2) antimateriel. Chemical antipersonnel NLWs are intended to dissuade, temporarily inhibit, incapacitate, or otherwise impede—with no lasting side effects—individuals and crowds from taking certain actions. Chemical antimateriel NLWs are intended to disable, neutralize, or otherwise prevent the operation of electronics, engines, networks, and so on, in vehicles or infrastructure. The Army supported much exploratory work over the past few decades and demonstrated some very promising ideas. Development activity by the Edgewood Chemical and Biological Command (ECBC) on agents for NLWs has been markedly reduced in recent years, however, with the adoption of the Chemical Weapons Convention (CWC).

Classes of compounds having potential as antimateriel NLWs that have been examined include combustion modifiers, anti-additives, fuel contaminants, lubricant contaminants, viscosity-enhancing agents, depolymerization agents, and abrasives that might be used against engines and vehicles. Corrosive agents, depolymerization agents, and embrittlement agents could be used against a wider range of infrastructure.

Classes of compounds with potential for non-lethal antipersonnel use include riot control agents, malodorants, and calmatives. Riot control agents (RCAs) include chemicals that irritate mucous membranes and cause lacrimation, irritation, or inflammation. RCAs produce rapid sensory irritation or disabling physical effects that disappear within a short time following termination of exposure. They are well studied as a class, and many highly effective compounds with large safety margins have been identified. Most commonly known are oleoresin capsicum (OC), the active agent in hot peppers; chloroacetophenone (CN); and o-chlorobenzylidene malononitrile (CS), or tear gas. Because of its persistence after application, CS has largely been replaced by OC, which has had recent, publicized use by civilian police agencies.

ECBC and other groups have studied malodorants, and many compounds with repulsive smells have been identified. Some of these materials are the active ingredients in the most disagreeable natural odors, and some are synthetic creations. Tests have shown that the repulsiveness of a particular compound to a person depends largely on the cultural background of the test subject. For example, manure is used as a fuel in some countries—so residents in those countries are desensitized to a smell that is repulsive in other cultures. In addition, the olfactory sensitivity to many malodorants lessens with extended exposure, and the degree of repugnance diminishes. Mixtures of malodorants, a mixture of a malodorant and an irritant, and/or concepts of operations that avoid successive use of the same malodorant within a specific time frame could circumvent these limitations.

Calmatives[6] represent a class of chemical substances that offer strong potential as effective NLWs. Major research and development (R&D) issues involving the use of calmatives are (1) the quantification of the effectiveness and margin of safety for these materials and (2) the development of the method of delivery that can rapidly provide the appropriate dose.

The physiological effects of all calmatives that have been examined occur as a result of depression of the central nervous system, accompanied by mood alteration and respiratory depression. A review of some potential calmatives was published in 2000.[7] High concentrations of calmatives in the body can lead to extended loss of consciousness or, in extreme cases, death. Safe yet effective applications of NLWs should limit exposures to well below those levels. The generally desired ratio of exposure between an effective dose and death is on the order of 10^3 to 10^4. (By comparison, the margin of safety for exposure to RCAs such as the lacrimator CS is about 2,500 to 30,000 dose units.[8]) Research carried out 10 to 15 years ago at ECBC began to examine the use of additional chemicals ("antagonists" mixed with "agonists") that would reduce the effect of respiratory depression, leading to acceptable margins of safety. The principal effect was still unconsciousness, which is unacceptable under most interpretations of the CWC. The research was not extended to the concept of mood alteration short of unconsciousness.

The use of calmatives had previously been envisioned in connection with hostage situations and for use with "unmanageable" prisoners, but not for riot situations in which incapacitated individuals might be trampled or crushed in the rioting. In fact, research on the use of calmatives for peacekeeping situations has been practically nonexistent. To elicit the desired level of mood alteration without causing a dangerous level of respiratory depression (i.e., calming while maintaining consciousness) requires a tight control on dose level. The time of onset of mood alteration depends markedly on the method of delivery as well as on the type of calmative used. Inhalation leads to the most rapid onset of symptoms—on the order of 1 minute after exposure for certain fentanyls. With other methods

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[6]Primary sources of information: Ken Collins, Gene Olajos, and Larry Bickford of the Edgewood Chemical and Biological Command, and Joseph A. Rutigliano Jr., International and Operational Law Branch, Headquarters, U.S. Marine Corps.

[7]Lakoski, Joan M., W. Bosseau Murray, and John M. Kenny. 2000. *The Advantages and Limitations of Calmatives for Use as a Non-Lethal Technique,* College of Medicine, Hershey, Pa., and Applied Research Laboratory, Pennsylvania State University, State College, Pa., October 3.

[8]In dose units: typically, with a respiratory agent exposure characterization of (mg – min)/m^3, a dose unit multiplies this by an assumed inhalation of 20 liters of air in 1 minute.

of delivery, such as absorption through the skin, 3 to 5 minutes is required for the onset of symptoms. However, a delivery method based on absorption through the skin could lead to contamination of U.S. personnel who come into contact with areas that have been exposed.

Directed-Energy Technologies

NLWs utilizing directed energy may be divided into three categories for the purposes of understanding applications and effects: (1) low-energy lasers and incandescent devices; (2) high-energy lasers; and (3) high-power millimeter-wave and microwave devices.

Low-Energy Lasers and Incandescent Devices

The category of low-energy lasers and incandescent devices includes laser dazzlers and flash grenades that use intense visible light to temporarily blind or disorient a person. Laser dazzlers often use diode-laser sources of radiation at far-red wavelengths near 600 nanometers (nm) or solid-state lasers such as frequency-doubled neodymium:yttrium aluminum garnet (Nd:YAG), which produces green light at 532-nm wavelength. Current models are handheld devices resembling flashlights, or rifle-mounted models designed to mount much like a telescopic sight. Following are some examples:

- The Saber 203 laser illuminator utilizes a diode-laser source that operates at red wavelengths and fits onto the grenade launcher attached to a rifle. It creates glare and flash-blinding that cause adversaries to protect their eyes and slow their advance. It was used in Somalia during the withdrawal of UN forces and has been effective largely because illuminated subjects believed that deadly force would follow the beam of light. Because of concerns over eye safety and minimal effectiveness during daylight, it has not been fielded for standard use.
- The hinder adversaries with less-than-lethal technology (HALT) system, similar to the Saber 203 dazzler, also uses a 650-nm (red) wavelength diode source. HALT is designed to mount on an infantry rifle directly below the gun barrel so that either the laser dazzler or the rifle may be used. Future plans for HALT include the capability for dual red and blue wavelengths that flicker off and to mitigate filtering by single-wavelength goggles.
- The Dissuader uses a laser-diode source similar to that of HALT, operating at red wavelengths, and operates much like a handheld flashlight.

A different approach to laser dazzlers, the proposed veiling glare system, would use a laser designed to produce violet light at 360 to 440 nm. At sufficiently high intensities, light at these wavelengths induces fluorescence in the human eye, which, in turn, produces diffuse, defocused light in the retina, appearing to the subject as omnidirectional. So far, this approach has been tested only in cadaver lenses. Although the fluorescence effect is known and documented, the potential for optical damage to the retina or other portions of the eye remains uncertain.

Unlike the veiling glare system, flash grenades produce a single intense burst of incandescent light, most often by the explosive combustion of some sort of fuel, and a significant pressure concussion accompanies the flash. An alternative approach utilizing a fuel-air mixture containing a metalized powder would reduce the potential for unanticipated injury by reducing the concussion pressure by a factor of 100.

High-Energy Lasers

In this report, "high-energy laser" refers to a system with sufficient energy (and/or power) to ablate, melt, or burn material. Such systems can be lethal if directed against human beings. Their use as NLWs is intended for applications such as bursting automobile tires, rupturing fuel tanks, selectively cutting through electrical or communications lines, or setting fires. The advantage of such a system, if achievable, would be its capability for selective and precise targeting. A frequently cited example of such targeting involves a military convoy operated by armed soldiers holding civilian hostages. The laser system would rapidly sweep along the convoy, selectively targeting vehicle tires, tracks, and weapons, while avoiding injury to the hostages.

The proposed approach to this type of system is the advanced tactical laser (ATL). Although still in the conceptual development stage, ATL would utilize a COIL. The laser, its chemical fuel, and laser beam director would be sized to fit on an aircraft platform such as an Osprey tilt-rotor craft or a C-130 transport. For the initial version of the ATL, the targets would be selected by a human operator who viewed the scene through a separate aperture co-aligned with the laser beam director. The operator would control the laser pointing using a manual designator. In more advanced versions of ATL, target selection could also be accomplished automatically using target-recognition and tracking software.

Several issues associated with atmospheric propagation are likely to limit the effectiveness of ATL as currently envisioned. The first is atmospheric absorption. At the COIL wavelength, atmospheric absorption will heat the column of air through which the beam passes; this heated air will defocus the beam, through a mechanism known as "thermal blooming," and will reduce the intensity on the target. Thermal blooming could be compensated for to some extent with adaptive optics, but that approach introduces significant complications to the system design. The second issue concerns the ability of ATL to be pointed precisely. A limiting effect is atmospheric turbulence along the propagation path; this turbulence causes high-frequency beam "jitter," which reduces the intensity on the target. Vibration disturbances on the aircraft platform itself will also contribute to beam jitter, further reducing the intensity on the target. Finally, for ATL to operate in the field, serious logistics issues would have to be addressed. The COIL fuel is composed of a number of caustic chemicals that require careful storage and handling. Although the technology to meet these requirements is available, they would be a concern for a system deployed to areas that lack proper handling systems.

A second class of high-energy laser systems for antipersonnel application is designed not to cause damage directly, but rather to produce a kinetic shock through a laser-induced plasma. One such proposed system is the pulsed-energy projectile (PEP). PEP would utilize a pulsed deuterium-fluoride (DF) laser designed to produce an ionized plasma at the target surface. In turn, the plasma would produce an ultrasonic pressure wave that would pass into the body, stimulating the cutaneous nerves in the skin to produce pain and induce temporary paralysis. The proposed PEP system would accomplish this at extended ranges.

Another proposed system is the pulsed impulsive kill laser (PIKL). PIKL is also at the feasibility-study level.

High-Power Microwave and Millimeter-Wave Technology

This class of NLWs—high-power microwave (HPM) and millimeter-wave technology—can be grouped into two subcategories: (1) those designed to disrupt electronic systems, such as communications and computer networks; and (2) those designed to produce a physiological effect on an individual.

Applications in the first category (electronic disruption) include the capability of disabling or destroying electronic equipment. All sensitive electronics—including computers, cell phones and radios, Global Positioning System (GPS) receivers, and engine ignition systems—are potential targets. HPM systems would provide this capability without the accompanying blast effects, physical damage, or death to nearby personnel characteristic of explosive or other high-kinetic-energy devices. HPM systems designed to produce these effects would utilize conventional millimeter-wave and RF generators combined with a suitable transmitter, such as a microwave horn or antenna. Unconventional approaches to generating and delivering HPM include Marx banks or explosive devices that would produce a single, intense pulse; they are usually referred to as electromagnetic pulse (EMP) devices.

Some systems designed to produce physiological effects operate at frequencies corresponding to millimeter waves in the range designed to be absorbed by the skin or at lower frequencies designed to produce resonance inside the body. VMADS is a system of the first type. It utilizes a microwave generator and an operator-steerable antenna designed to produce a narrow beam width beyond small arms range. The VMADS effect causes an intense but non-lethal burning sensation in a quick exposure. Potential applications are crowd control or perimeter protection around an airfield or other sensitive area.

One area of concern with millimeter-wave devices designed to induce biological effects is the potential for ocular damage such as corneal lesions, as well as the inadvertent exposure of targets at close range, which could lead to severe burns or other injuries. To be effective, the NLW must operate at intensities sufficient to induce avoidance, but below the threshold for serious injury.

Acoustic Technologies

Acoustics have been considered as a non-lethal weapons technology to disperse crowds and to temporarily startle or incapacitate individuals. A wide variety of effects have been explored or proposed. Acoustical energy at audible frequencies (about 20 to 16,000 hertz (Hz)) strongly couples into the ear; continuous sound in this frequency range can cause pain at a threshold of approximately 135 dB. Other frequencies—ultrasound and infrasound—have also been studied. Vortex ring generators have been investigated as well. Explosive flash bangs provide a short, high-intensity acoustic pulse. Coupling mechanisms into the body have been proposed: for example, mechanically coupling and vibrating internal organs with infrasound, utilizing resonances in the airway to entrain breathing, heating the skin ultrasonically, and bone conduction at very high acoustic intensities.

The concept of acoustic NLWs has focused on acoustic generators projecting sound downrange to affect crowds, to provide area denial, or to clear facilities. Generators that have been explored for producing these high intensities include sirens, whistles, pulse jets, vortex generators, explosives, and fuel-air devices. For interior use, very high intensity acoustics (>170 dB) have been investigated as an access-delay technology for physical security systems.[9]

Development of acoustic technologies for non-lethal weapons applications in air has generally not been successful for several reasons. Most significant is that there are no demonstrated extra-aural bioeffects that significantly affect adversary behavior. Driving audible acoustic intensities to levels above the hearing pain threshold can be effective, but it can also permanently damage hearing or can be easily countered. Other issues with sonic generators include exposure of friendly forces to the energy, difficulties in focusing the energy downrange, the rapid decrease in intensity with range, and the power requirements to generate and maintain very high continuous acoustic intensities.[10]

Underwater applications present a potentially more promising scenario, however, due to the increased coupling of acoustic energy. Past investigations have considered the use of ship sonar against underwater threats. Also being

[9]Cutler, R.P. 1999. "Tests of High Power Acoustics Sources," Sandia National Laboratories, Albuquerque, N.M., September 30.

[10]Busic, John. 1997. "Technology Assessment of Acoustics as a Non-Lethal Weapon," U.S. Marine Corps Joint Non-Lethal Weapons Directorate, Quantico, Va., December.

investigated are underwater acoustic sources as warning or non-lethal options against such threats. Unknowns include environmental effects on fish and marine mammals.

Electrical Technologies

The non-lethal electrical methods identified in Table B.1 (Appendix B) have been developed for tasks as diverse as stunning individuals, stopping engines of moving vehicles, and temporarily knocking out electrical grids and power generation.

The class of NLWs that injects electrical energy into a human at high voltage, high frequency, low current, and with very short pulses is generally known as the stun gun. There are approximately a dozen manufacturers of such weapons, and each uses slightly different pulse parameters. The stun gun incapacitates an individual by stimulating nerve cells proximate to the discharge region and temporarily overriding normal motor control signals, causing uncontrollable muscular contractions. Complete recovery occurs within about 15 minutes after the stun gun is turned off. Off-the-shelf stun guns are widely used in law enforcement because of their high degree of effectiveness. Their safety has received a moderate amount of attention in safety documentation by manufacturers, but little to no actual data are found in the peer-reviewed literature, and basic mechanisms are not well studied. The effectiveness of these systems is severely limited in military operations by the fact that they can only be used at arm's length. Somewhat greater standoff distance is afforded by newer stun gun munitions, which can be projected as darts (two per round with trailing wires) with an effective range of 12 to 15 m or "air" tasers with a range of about 20 m, although 90 to 100 m would be more useful for military applications. A more novel concept is a proposed cylindrical "dart mine," which, when triggered, would spew darts in all directions for area denial. Its effectiveness remains to be established.

For stopping vehicles, pulsed-current devices have been employed to inject an electrical discharge from a capacitor into the electrical system of the engine of a moving vehicle, causing the engine to misfire and stop. Direct electrical contact of the device with the engine block must be achieved; this creates a requirement for an effective delivery system. This approach works for vehicles with modern electrical systems, especially those utilizing a computer. In most cases, the computer/electrical system is temporarily interrupted, and the engine can be restarted. The approach does not work as well—or at all—on vintage vehicles or diesels. In law enforcement applications of vehicle stopping, two systems have been employed: (1) stationary contact points positioned to anticipate a passing vehicle, and (2) small delivery vehicles designed to overtake and make contact with an offending vehicle. If the route of a threatening or fleeing vehicle can be predetermined—as for an entryway to a garage or a driveway to a building—then a strip containing the electric discharge system can be put in place ahead of time. When the route cannot be predetermined, the pulsed-current device must be launched in real time from a ground-based chase vehicle or helicopter. While there appear to be opportunities for the use of such devices in military applications—for example, missions geared to protecting U.S. embassies or operational airfields and docks—the main impediment is the difficulty of delivery. In such cases, electrified fences may also prove useful.

Barriers and Entanglements

Barriers have been used as non-lethal weapons devices for many years by the Services, law enforcement and corrections, and the U.S. Department of Energy (DOE) in physical security applications. Existing and potential non-lethal mission uses of barriers and entanglements are extensive. Barriers can be used to form a line of demarcation, to separate adversaries from friendly forces, to delay adversaries from gaining access to an area, to secure facilities, to stop vehicles, to disable boats, and to serve in many other applications where delaying an adversary's action is required. Barriers encompass a broad range of devices, materials, and systems, ranging from simple devices, such as caltrops, to complex barrier systems utilizing movable concertina blankets and portcullises. They can often be made more effective by combining technologies, for example, concertina used in combination with an obscurant as a barrier in an interior application.

Barriers may also include materials applications for the purpose of delaying adversaries. Well-known examples are sticky foams and rigid foams for rapidly blocking areas or gluing other barriers in place. Low-coefficient-of-friction materials can act as barriers against the transit of personnel or vehicles. High-expansion-ratio, high-strength materials are of particular utility for non-lethal use, because the transported volume of these materials is far less than the dispensed volume.

Many effective barriers utilize high-strength materials (e.g., steel) and mass (e.g., concrete or earth) to effect a needed delay. A challenge in applying barriers and entanglements to non-lethal uses is to develop effective barriers with weights and stored volumes acceptable for staging and deploying the barrier. Re-use is desirable in many applications to reduce deployment costs of barriers and to minimize storage volume.

Rapid deployment is often the major challenge for effective barrier use. For vehicle barriers or entanglements, rapidly deployable systems are necessary for putting barriers in place before a vehicle can enter a secure zone or for allowing timely interdiction of moving land vehicles or watercraft. Precision delivery of barriers may be required. An example is the running gear entanglement system (RGES), which has proven to be effective in temporarily stopping small, fast watercraft. A challenge with a RGES is to integrate the barrier with capable delivery systems providing rapid and accurate delivery. The Coast Guard, with assistance from the Naval Surface Warfare Center Dahlgren Division (NSWCDD), is developing helicopter-based deployment systems to accurately and safely emplace the RGES in order to stop fast boats. In some situations, remotely piloted watercraft would be the platform of choice in deploying RGES-like barriers. Such watercraft might also serve as barriers themselves, in much the same way that police use squad cars to channel, block, and/or ram suspect vehicles.

Artillery has been used to deploy large capture nets in proof-of-concept demonstrations for the Army. Similar use of naval cannon—to deploy entangling rope arrays near approaching boats, both to warn and to entangle running gear should a boat cross the deployed barrier—might be envisioned.

Enabling Technologies

Technologies for Delivery of NLWs

Important characteristics of delivery systems include range, payload capacity, payload flexibility, delivery accuracy, reusability, and specific applicability to allow deployment of a particular non-lethal weapons technology. By their nature, non-lethal weapons technologies often have limited range and some variation in effects. This implies that non-lethal weapons delivery systems are particularly important in order to maximize the effects of the weapon on target.

Many different delivery system technologies have potential for supporting employment of non-lethal materials or weapons. At the low end of the spectrum are hand-held weapons for firing low-kinetic-energy munitions, chemical dispensers, and electrical stun devices. Effective ranges of these devices range from contact to scores of meters. Intermediate-range weapons include grenade launchers, mortars, and larger-caliber guns. These larger-caliber systems allow some additional volume for non-lethal payloads; however, the kinetic energy of the casings of these munitions can pose a significant personnel injury risk. Directed-energy antipersonnel platforms (e.g., VMADS and PEP) also fall into the category of delivery of hundreds of meters. Finally, there are systems that can deliver a non-lethal weapon technology a kilometer or more. These include large-caliber guns, naval cannon, watercraft, aircraft, and unmanned platforms.

These delivery options have been identified and cataloged in other studies. For this review, delivery systems are highlighted (see Table 2.1) on the basis of their expected capability for providing deployment of an array of non-lethal materials or weapons. Extended range—a very important requirement for many NLWs, especially for naval expeditionary force missions—is another important factor for including a particular delivery system. The options and their advertised capabilities are presented in Table 2.1.

Delivery systems for NLWs sometimes require specific development and integration with the non-lethal technology to optimize the effectiveness of delivery for particular use scenarios. Examples are mortar or large-caliber guns for

TABLE 2.1 Delivery Systems for Non-Lethal Weapons

Category	Development Maturity for NLWs	Effective Range	Accuracy	Payload Flexibility	Reuse (√ = reusable)	Collateral Damage Potential
Weapon systems to deliver materials						
Grenade launchers	Extensive	Hundreds of meters	Medium	Low	√	Low
Mortars	Moderate	Kilometers	Medium	Low	√	Medium
Missiles, rockets	Moderate	Kilometers	Medium	High		High
Bombs	Low	Kilometers	Medium	High		High
Guns (rifles, shotguns)	Extensive	Hundreds of meters	High	Medium	√	Low
Guns (large caliber)	Low	Kilometers	High	Medium	√	High
Torpedoes	Low	Kilometers	Medium	Medium		Medium
Mines	Moderate	Meters	Low	Medium		Low
Special (multiple delivery) systems	Moderate	Hundreds of meters	Medium	Low		Low
Platforms to deliver materials						
Aircraft						
Manned	Extensive	Kilometers	High (with precision munitions)	High	√	
UAVs—Dragon Drone, FASM, LEWK, SWARM	Moderate	Kilometers	High	High	√	Low
Micro air vehicles	Moderate	Kilometers	High	Low	√	Low
Unmanned parafoil	Moderate	Kilometers	High	High	√	Low
Surface vehicles	Extensive	Kilometers	Medium	High	√	
Surface vessels	Extensive	Kilometers	Medium	High	√	
Robotic vehicles	Moderate	Kilometers	High	High	√	Low
Small, fast surface vessels, tele-operated or robotic (Roboski)	Low-Moderate	Kilometers	High	Medium	√	Low
Small unmanned underwater vessels	Low	Kilometers	High	Medium	√	Low

NOTE: Acronyms used in this table are spelled out in Appendix E.

which non-lethal system packaging and collateral effects of fragmented casing would need to be considered.

Systems that appear to provide offensive capability for delivery of non-lethal payloads are unmanned platforms—for example, robotic platforms, UAVs, unmanned watercraft, and UUVs. Advantages of robotic platforms include reduced risk to operators, rapid response if the platforms are compact and high speed, and reduced manpower needs if the platforms are autonomous. UAVs provide capabilities for either ground or shipboard non-lethal munitions to be delivered accurately to a specific location. UAV technology is being developed for many other applications, and several non-lethal payload deployments have been demonstrated from UAVs. Non-lethal technology applications will not drive UAV development; instead, non-lethal payloads will be integrated into UAV platforms that provide the required functionality of payload capacity, range, and delivery mode.

For Navy ship protection in particular, unmanned surface craft and UUVs could afford significant capability in enforcing the multilayered protection strategy for ships in port, at anchor, or even underway in littoral waters (see Section 1.2). These craft could interrogate, assess, and warn of potential threats, deliver and apply a range of escalating non-lethal weapons technologies, and, ultimately, incorporate a lethal response. Smart buoys, teleoperated or autonomous robotic jet skis ("Roboskis"), or modified launches could also be envisioned as potential non-lethal delivery platforms in the Navy context. Autonomous robotics and cooperative robotics are more advanced technologies that can be incorporated into delivery platforms to enhance operator control and information management, assist with addressing multiple threats, and improve response times to incoming threats.

Sensors and Non-Lethal Weapons

Sensors have a major effect on the conduct of non-lethal warfare, but little has been done to develop sensor/NLW integration to a level comparable with that of the sensor/lethal weapon analogue. Sensor systems should play a role in nearly all aspects of NLW use. They can provide warning, localization, and tracking of potential enemy threats, as well as detecting and identifying adversaries to permit closed-loop tailoring of the desired effect of the NLW. Sensors embedded in the guidance and control systems allow for the precision engagement of hostile targets with NLWs.

Although both lethal and non-lethal weapons depend on sensors for cueing, targeting, guidance, fuzing, and/or effects assessment, NLWs can potentially benefit more for several reasons. Many NLWs have a more limited range within which they are effective, either because they must be released or activated near their target or because the range of safe and effective concentrations of some non-lethal weapons agents is relatively narrow. Sensors remotely placed near targets can also be used to provide real-time assessment of the application and effects of

NLWs, since visual observation alone may not determine if the desired and necessary effect has been achieved.

One form of real-time feedback could be the rangefinder system on a rifle delivering a blunt-impact projectile. By using the output of the rangefinder system to adjust the propellant or gas pressure, blunt-impact projectiles could be delivered at the target with the same momentum regardless of distance to the target. Although more costly than today's rifle-fired NLWs, such a system could greatly reduce the number of unintended serious injuries and fatalities. Similarly, if a target is moving, small, disposable, passive or active sensors can be used to track an individual, a group, or vehicles (on land, sea, or under water) by affixing an appropriate marker or tag to the target.

One could imagine several future scenarios that illustrate the usefulness of combining sensors with NLWs:

- A suspicious boat continues on a course toward a U.S. Navy ship in a foreign port and crosses the perimeter of the outer security zone, arousing concern. A small UAV, which is loitering beyond the warning zone around the ship, is quickly maneuvered by the UAV operator and makes a low pass over the boat. Onboard, the UAV electro-optical imagers with telephoto lenses get a close look over the stern of the boat and into the cockpit. A red laser dissuader beam is activated on the UAV, painting the cockpit of the boat with a red warning glare. The boat operator responds and changes course away from the ship.
- In a difficult crowd control situation, the decision is made to use calmatives, which must be applied within a specific range of concentrations. To ensure proper dosing, a small UAV is launched, dropping remote sensors containing chemical "laboratory" electronic chips that give chemical analysis feedback to adjust the release level of calmative agents in the target area.
- In a humanitarian operation involving delivery of food to starving people, an unruly crowd forms. A VMADS unit is used to control the crowd surrounding the convoy delivering supplies. To make sure that no one in the area is overexposed, small pre-placed microwave sensors continuously monitor the exposure level from several points in the area and provide real-time measurements of beam intensity in the target area to the VMADS operator.

A vast amount of work has been done on sensors, especially those based on the electromagnetic spectrum. Much of that work, sponsored by DOD, is applicable to non-lethal weapons systems. Of particular interest are acoustic, thermal, imaging, microwave, explosives, and chemical detection sensors that can be remotely deployed or focused. Low-cost, expendable sensors that could be dispensed from small, low-flying, remotely piloted vehicles or robotic surface vessels would be useful for many types of non-lethal weapons missions. Most or all of the desired sensor operational features (day/night, all weather, antijam, and so on) to support lethal force application carry over to non-lethal use, but with the more stringent requirement for real-time fusion and feedback to enable the switch from non-lethal to lethal force when necessary.

2.2 HEALTH EFFECTS AND BIOSUSCEPTIBILITIES

"Susceptibility" is used in this report to refer to specific responses of the human system to exposure to a form of energy or to a chemical. Knowledge of susceptibilities is important, because they form the biophysical/biochemical basis for developing antipersonnel NLWs. Susceptibilities are rarely known a priori but are discovered either by methodical evaluation of a biological system when it is exposed to an energy form or a chemical, or by accident. For example, it was generally known from fundamental physics that radio frequency exposures resulted in heating tissue.

Once a biological susceptibility is discovered, the parameters of exposure and response can be explored to evaluate whether the susceptibility can be used as the basis for a new weapon. Likewise, once discovered, the susceptibility can be studied to determine the potential health-effects consequences of using the knowledge of this susceptibility to develop a weapon. In an ideal situation, a biological susceptibility can be exploited to produce an effective non-lethal weapon that results in low, reversible, and predictable levels of human harm.

This section provides an abbreviated summary of the state of knowledge of health effects for non-lethal weapons phenomenologies. More detail for each area can be found in Appendix C.

From Kinetic-Energy Sources

While significant efforts have been made to understand basic principles of the trauma that can be caused by kinetic energy—for example, in automobile collisions or sports injuries—much of that work has involved masses and velocities much different from those of non-lethal beanbags and rubber bullets. Some recent work consists of phenomenological observations of human surrogates—animals, cadavers, or physical models. The scientific basis for developing more effective but less harmful weapons does not now exist. A sound basis, proposed by the research community, can be developed using (1) modern computational techniques to create finite element models of humans and animals, and (2) detailed impact studies using animals for parametric pain evaluations and using cadavers for parametric tolerance evaluations.

From Directed-Energy NLWs

The first radio frequency non-lethal weapon, VMADS, is based on a biophysical susceptibility known empirically for decades. More in-depth health effects studies were launched only after the decision was made to develop that capability into a weapon. The heating action of RF signals is well understood and can be the basis for several additional directed-energy weapons. Leap-ahead non-lethal weapons technologies will probably be based on more subtle human/RF interactions in which the signal information within the RF exposure causes an effect other than simply heating: for example, stun, seizure, startle, and decreased spontaneous activity. Recent developments in the technology are leading to ultrawideband, very high peak power, and ultrashort signal capabilities, suggesting that the phase space to be explored for subtle, yet potentially effective non-thermal biophysical susceptibilities is vast. Advances will require a dedicated effort to identify useful susceptibilities.

Similarly, much is known about the effects of single-frequency commercial lasers on the human eye. However, new developments are leading to multiple-frequency lasers, as well as to ultrashort-pulsed systems; effects data are lacking for both. Identification of optimal non-lethal ocular effects will require a dedicated effort, not now being carried out, to explore the biophysical susceptibilities over the substantial phase space of both lasers and non-coherent systems.

From Chemical NLWs

Two materials, OC and CS, are currently classified as riot control agents (RCAs), although OC is not approved for Army use by the Army Surgeon General. Empirically and in terms of mechanisms of action, RCA effects are reasonably well understood, with margins of safety well established. The mechanisms of action of calmatives and malodorants are also generally understood, but no active program to optimize their use for treaty-compliant applications or to improve delivery means was identified by the committee.

From Acoustics

Traditional acoustic methods have not been successful in causing reliable non-lethal effects in any but highly restricted conditions (e.g., when flash bangs are used). This is true despite decades of anecdotal references describing debilitating effects of certain low frequencies. No program is currently exploring more basic mechanisms for traditional acoustic susceptibilities.

Two acoustic technologies might be useful as psychological weapons systems. A technology, which is commercially available, operates by crossing two sonic beams at the location of the receptor to produce an audible voice. These technologies might be used with one another or with other non-lethal weapons technologies in synergistic ways to cause disorientation or psychological effects.

From Electrical NLWs

The open literature contains little discussion about the biophysical mechanisms by which widely used stun gun systems create their effect. Collectively, the manufacturers of stun guns have sponsored investigations that provide a basis for improved safety and efficacy. It is estimated that approximately 2,000 volunteers have tested stun guns intended for human use without significant aftereffects.

Psychological and Behavioral Effects

The use of NLWs is intended to cause a desired change of behavior in the targeted group or individual. It is important to understand and characterize the likely types of behavior caused by the use of an NLW, especially in crowds or with repeated use. Knowing the range of psychological responses to a given NLW can also point to methods for enhancing the effective use of that system. The committee identified little direct effort supporting psychological understanding of NLWs.

2.3 JOINT NON-LETHAL WEAPONS DIRECTORATE

The Joint Non-Lethal Weapons Directorate functions as the DOD focal point for NLWs and is the organization through which the Services coordinate and integrate the development of all non-lethal weapons programs.[11] The Commandant of the U.S. Marine Corps serves as the overall executive agent for non-lethal weapons, exercising oversight through an integrated product team that is chaired by a three-star Marine general and has members who are senior leaders from the other Services.

When created in 1996, the JNLWD was under great pressure to produce tangible results as quickly as possible. The urgent need for NLWs by troops committed to existing operations drove the early activities of the organization. It engaged the problem of NLWs conservatively and focused on “the low-hanging fruit” that could be picked from relatively mature programs throughout DOD and within law enforcement, government laboratories, and defense industries.

The JNLWD deserves praise for its accomplishments to date. Despite limited resources,[12] it has moved since 1997 from starting with a zero-based budget to completing a Joint Mission Area Analysis in 2000 (results discussed in Sections 2.1 and 2.9). It evaluated all ongoing non-lethal weapons programs, moved many forward in the development process, and terminated those undeserving of

[11]As a result of Joint Service Memorandum of Agreement dated January 21, 1997, the directorate maintains sufficient contact for Service-unique systems specifically developed for strategic application and provides program insight rather than financial oversight.

[12]The entire annual budget for the directorate has been between $17 million and $25 million per year and is projected at $25 million to $35 million per year through the future year defense program (FYDP).

additional funding. Working with the Services, the directorate deployed to the field a number of non-lethal weapons capabilities, including munitions for crowd control, portable barriers for stopping vehicles, pepper spray, shields, and low-kinetic-energy bullets. Capability sets or kits of NLWs and training programs for their use have been developed for Marine and Army units.

The JNLWD recognized the shortfalls in understanding the effects of NLWs on humans and established the Human Effects Review Board (HERB) and the Human Effects Center of Excellence (HECOE) at Brooks Air Force Base, San Antonio, Texas, to focus research in this area. It has engaged in many activities—including modeling and simulation, war games, experiments, and concept exploration programs—to investigate the potential of NLWs for applications to operational missions. It has supported a technology investment program to stimulate new ideas. In addition, it has established information exchange relationships with countries that have had endemic problems of instability and substantial experience using NLWs, such as Great Britain and Israel.

Legacy Programs

Shortly after its establishment, the JNLWD led a review of all non-lethal weapons programs through a joint forum evaluation process.[13] Following is a list of the programs constituting the legacy from non-lethal weapons programs at the time, with a synopsis of each program's current status:

- *40-mm non-lethal crowd dispersal cartridge*. Continues in development, with the U.S. Army as lead Service.
- *Acoustic bioeffects and acoustic generators*. Terminated in 1999 after a detailed technical review, which determined that there was a lack of demonstrated generator capability and of bioeffects.
- *Modular crowd control munitions*. Provide a non-lethal derivative of the Claymore mine. A formal acquisition program was initiated, with the Army as the lead Service. These munitions have been delivered to the field.
- *Ground-vehicle stopper*. Transferred to the Army for additional R&D when an independent technical review flagged issues of device size, variable target effects, and personnel safety.
- *Vessel stopper*. Initial program on use of running gear entanglement system (RGES) started by Naval Undersea Warfare Center in 1994. A general mission needs statement was approved in April 1997, and a specific capstone requirements

[13]A reviewer of this report noted work in the early 1990s by the Defense Nuclear Agency, the predecessor of the Defense Threat Reduction Agency, which contributed to the formation of the JNLWD. This and presumably other early work was not briefed to or found by the committee in reviewing the history of the JNLWD. The JNLWD should find and review this earlier work to assess its relevance in light of the evolving security environment.

document (CRD) followed in August 1999. An assessment by the Fifth Fleet recommended further development of entanglements for small, fast boats. Exhaust stack blockers (ESBs) for large-displacement vessels were also of interest; however, after exploratory testing, these were terminated because of low operational utility. In contrast, the RGES successfully passed an independent technical review, and it continues to be developed by the Naval Surface Weapons Center and the U.S. Coast Guard with JNLWD support. Another concept being explored is the use of RGES for perimeter ship protection (as discussed in Section 2.4).

- *Portable vehicle-arresting barrier*. Also called Speed Bump; provides a portable barrier that can be rapidly erected using a pop-up net. It is now in a formal acquisition program, with the Army as the lead Service; units are being delivered to the field.
- *Vehicle-mounted active denial system*. Initially begun by the Air Force Research Laboratory to investigate active denial technologies for physical security applications using millimeter-wave technology. Even in its prototype stage, VMADS has stimulated considerable operational interest. The program has passed a series of assessments, including independent technical assessment, assessment by the Judge Advocate General, bioeffects assessment, and legal and policy reviews. It is being moved ahead to advanced concept development and demonstrations by the Air Force, and the Navy is exploring the concept for force protection applications.
- *66-mm vehicle-launched grenade*. U.S. Army program to produce a non-lethal grenade capable of being launched from a vehicle. It moved to formal acquisition and is now in production.
- *Bounding non-lethal munitions*. M16A2 non-lethal mine variant, called the Bouncing Betty, terminated because of unacceptable development costs.
- *Canister-launched area denial system (CLADS)*. Volcano-type launcher used for rapid deployment of non-lethal mines; terminated due to unacceptable development and procurement costs. The general concept is still under consideration.
- *Foam applications*. Evolved into two separate programs: slippery foams and rigid foams. The former is in a concept exploration phase, and the latter is in an acquisition program.
- *Vortex ring gun*. Investigated the use of the Mk19-3 for vortex delivery of non-lethal materials. It was terminated in 1998 because of unpredictable vortices and limits on effective range.
- *Under-barrel tactical payload system*. Pneumatic devices for delivery of various payloads from the M16A2 and M4 carbines. It was terminated because of limited interest by the Services.

Technology Investment Program

In 1998, the JNLWD established a technology investment program (TIP) with government laboratories, industry, and academia in order to generate new technology concepts for NLWs. Projects in this program include studies, laboratory tests, and field demonstrations. Those with potential are shifted into some appropriate phase of the acquisition process. Among the projects already completed are the following:

- *Non-lethal electromagnetic pulser.* A study for using a man-portable non-lethal electromagnetic pulser (NEMP) to disable vehicles.
- *Spider fiber.* A technology assessment of spider fiber genetic research.
- *Taser munitions.* A successful test of the ability to deliver high-voltage/low-current, incapacitating electrical pulses through military clothing. Transferred to a CEP for further investigation.
- *Overhead liquid dispenser.* A successful demonstration of the ability to disperse liquids rapidly over large areas (13-m-diameter circles) up to 175 m away. Transferred to a CEP for further investigation.
- *Pulsed-energy projectile.* A study on the use of a pulsed chemical laser to create a flash-bang effect on target. Recommended for a Pre-Milestone A acquisition program.
- *Combustible mortar.* A study on the use of combustible materials to reduce the lethality of the mortar shell body. Recommended for a Pre-Milestone A acquisition program.
- *Biomaterials survey.* A survey and documentation of biomaterials such as those derived from natural sources (e.g., use of high-strength fibers for immobilization of personnel or vehicles).
- *81-mm non-lethal mortar.* A successful development and demonstration of a composite-based mortar capable of delivering non-lethal payloads as far as 1.5 km while keeping the mortar shell itself non-lethal. Recommended for a Pre-Milestone A acquisition program.
- *Odorous substances.* A report on human testing of several malodorants. Transferred to a CEP.
- *Advanced tactical laser.* A feasibility study to determine the effectiveness of ATL in conducting non-lethal missions. Currently proposed for an advanced concept technology demonstration (ACTD) principally focused on lethal applications. (See discussion in Section 2.1.)
- *Non-lethal guided projectile.* A study on the feasibility, design, and analysis of long-range delivery of non-lethal payloads.

The JNLWD has several technology investment programs that are ongoing or are being initiated. They include the following:

- *Non-lethal loitering system.* An assessment of an autonomous delivery system for non-lethal applications.
- *Microencapsulation.* A demonstration of the ability to encapsulate non-lethal chemical payloads.
- *Front-end analysis.* A series of workshops and analyses culminating in a

database of potential riot control agents and calmatives, with emphasis on technology advances in the past 10 years.

- *Thermobaric technology.*[14] A feasibility study to determine the usefulness of thermobaric weapons to conduct non-lethal missions.
- *Veiling glare laser.* A study to demonstrate the ability of an ultraviolet laser to create a fluorescence-induced glare on excised human cadaver lenses.

Other JNLWD Technology Initiatives

In addition to the TIP, the JNLWD initiated other activities to evaluate and stimulate new technologies for non-lethal applications. The directorate established the Non-Lethal Technology Innovation Center at the University of New Hampshire in response to congressional direction. Over the next 2 years (2001 to 2003), the university will evaluate such areas as rigid foams and antitraction materials; foreign attitudes toward NLWs; and the applicability of nanotechnology and microelectromechanical systems (MEMS).

The directorate is working through the Small Business Innovation Research (SBIR) program with the U.S. Marine Corps Systems Command to explore a multisensory grenade and devices for tagging and tracking. Both initiatives have successfully been moved on for further investigation as part of a CEP for clearing facilities.

The JNLWD is leveraging three special technology programs of DOE—those on (1) the variable thrust cartridge, (2) the disruption of voluntary motion, and (3) non-lethal airburst munitions with variable reverse thrust propulsion. The directorate also has a memorandum of understanding with the National Institute of Justice for cooperative non-lethal weapons development.

Characterization and Assessment of Human Effects

The JNLWD recognized early the importance of characterizing human effects resulting from non-lethal weapons. These effects can include *health effects* on the weapon user, on human targets, and on humans near the target, as well as the *effectiveness* of the weapon in creating the intended response from the target. The understanding of health effects, while complex, is critical to the development and subsequent fielding of the weapons. Consequently, the directorate convened experts in different areas to address the need:

- *Human Effects Process Action Team (HEPAT).* A group of DOD medical research and acquisition experts assembled to review the process of characteriz-

[14] Thermobarics are explosive-like compounds that do not detonate but evolve their energy with significant thermal release over a relatively long time.

ing non-lethal weapons human effects and to recommend changes to ensure full characterization of non-lethal weapons effects. The team was disbanded after recommending formation of the Human Effects Review Board and Human Effects Center of Excellence.

- *Human Effects Review Board (HERB)*. A board consisting of one representative from each Service that reviews data on non-lethal weapons human effects specific points in the acquisition process and provides recommendations to the program manager. This board is analogous to the Navy's Weapon System Explosives Safety Review Board (WSESRB)
- *Human Effects Center of Excellence (HECOE)*. An organization hosted by the Air Force Research Laboratory, Brooks Air Force Base, to provide expertise on human effects to non-lethal weapons developers.
- *Human Effects Advisory Panel (HEAP)*. An independent panel of experts formed by Pennsylvania State University to provide advice to the JNLWD on human effects issues.

The activities and effectiveness of each of these bodies is discussed further in Section 3.1 as a part of the finding under "Programs for Effects Characterization."

The JNLWD has also supported the modeling of the health effects of kinetic-energy weapons; included are an interim total body model, a three-rib model, effectiveness modeling, and advanced kinetic modeling.

Non-Lethal Weapons Systems Effectiveness

Beyond establishing effects on targets, the JNLWD must address the broader range of issues associated with establishing military acceptance for NLWs. The military Services' willingness to develop and field non-lethal weapons systems will be determined by the systems' effectiveness in performing military missions. Military commanders will embrace non-lethal weapons systems that help accomplish missions with fewer casualties, increased speed, higher accuracy, reduced collateral damage, better cooperation from the local population, lower cost, smaller support requirements, or a greater overall probability of success.

This statement, however, is deceptive in its simplicity. The "effectiveness" of any weapon system, lethal or non-lethal, has many dimensions. In an era of tight budgets and strained logistics systems, new weapon systems bear a particularly heavy burden in establishing their effectiveness. In terms of resources, new systems must demonstrate their effectiveness to compete favorably for development and procurement dollars. In terms of logistics, commanders must view them as essential—deploying with a new weapon system could very well mean leaving an existing system behind.

A lack of understanding of effectiveness has the potential of being a "show-stopper." While any weapon may fail to perform as predicted, well-established methods underlie its ultimate fielding and support the expectation of its performance: those methods include experiments and training to develop and refine the concept of operations (CONOPS), tactics, and rules of engagement; logistics and maintenance; countermeasures assessment and development of counter-countermeasures; and so on. Of equal importance is an understanding of U.S. vulnerabilities should NLWs be used against the United States.

In its brief existence, the JNLWD has achieved notable success in this context. Marine Corps expeditionary forces now routinely train and deploy with non-lethal weapons capability sets. The Army also has plans to procure non-lethal weapons capability sets. Limited budgets and the urgency to field non-lethal weapons systems has understandably led the directorate to focus on fielding relatively simple weapons thus far: for example, non-lethal ammunition, flash-bang grenades, and riot control agents.

Experimentation has been instrumental in gaining understanding and acceptance of NLWs. The Marine Corps has had an active experimentation program for some time (Section 2.6), and wider awareness of the usefulness of NLWs is being accomplished through joint efforts supported by the JNLWD. For example, the Joint Forces Laboratory, a part of the Joint Experimentation Directorate (J-9) of U.S. Joint Forces Command, recently conducted experiments on low-collateral-damage weapons. Many of the weapons used in the experiment, such as slippery foam, were found to be effective in several mixed combatant/noncombatant environments. In another effort to stimulate experimentation, the JNLWD has helped incorporate models of existing non-lethal weapons capability sets into the joint conflict and tactical simulation (JCATS), a defensewide modeling and simulation program. The models have undergone verification and validation, and JCATS is ready for use as an analytical tool for the non-lethal weapons capability sets. The Army is leading a joint effort to study the capability sets, with particular emphasis on urban terrain. The JNLWD recognizes the value of continuing to fund experimentation. The directorate's budgets indicate that it plans to continue experimentation efforts.

The Services have also established a joint program to train users of the deployed non-lethal weapons capability sets. The inter-Service non-lethal, individual weapons instructor's course is offered several times a year at the U.S. Army Military Police School, which is located at Fort Leonard Wood, Missouri. The course covers training in equipment use, doctrine, and tactics, and also addresses public affairs, crowd control dynamics, and communication skills. It is structured to "train the trainers." That is, graduates of the course return to their units to train other unit members. For example, Marine Corps expeditionary forces receive training on non-lethal weapons capability sets during their deployments. To support instructors in the field, the school makes course materials available over the Internet.

The scope and location of the existing training program for NLWs are appropriate under current conditions. The deployed non-lethal weapons capability sets contain equipment that is designed for close-in use against individuals and crowds. The practice of training instructors who can then train end users is an economical, effective use of training resources that works well for new but relatively simple weapons.

As NLWs increase in complexity, however, the challenge of establishing their effectiveness increases even more dramatically. VMADS represents the first NLW with the potential for providing more than tactical, short-range capabilities for individual soldiers. Based on a new weapons principle, VMADS requires integration into an existing military vehicle and as an antipersonnel weapon must be understood in terms of its specific effects on the human body. For VMADS and other complex non-lethal weapons systems that could emerge in the future, the need to establish their effectiveness presents a far greater challenge than that for the earlier generation of NLWs.

Future Program Plans

For all the right reasons, the JNLWD has followed a strategy of nurturing more mature technologies for non-lethal weapons systems. However, it is clearly at a crossroads in its ability to move new capability into the field. On its present course, the directorate will soon be out of well-founded ideas to push toward development for several reasons: limited investments in R&D, the gap in characterization of the human effects of NLWs across the board, and the lack of resources for developing full systems concepts and for establishing their military effectiveness.

2.4 NON-LETHAL WEAPONS, FUTURE NAVAL CAPABILITIES, AND DEPARTMENT OF THE NAVY S&T

In 1998, the Department of the Navy reorganized the naval science and technology portfolio to focus more clearly and to engage users in the development of nearer-term capabilities through the future naval capabilities (FNC) process, while at the same time maintaining a balanced investment in less-mature, potentially high-payoff basic research managed by the Office of Naval Research (ONR). To enjoy the commitment of naval science and technology (S&T) funds, a technology must be approved in the FNC process or be deemed important for contributing to the elements of naval basic research (see Box 2.1). NLWs appear explicitly in only a single enabling capability, “ability to win or avoid engagements by weapons/platforms, asymmetric threats, and non-lethal weapons/threats encountered in the littorals,” within 1 of the 12 FNCs, Platform Protection. The list of supporting technologies within that enabling capability does not include an explicit non-lethal weapons program, although a few could contribute to some of the non-lethal weapons technologies recommended later in this report.[15] In addition, there is no mention of NLWs in the enabling capability “defeat expeditionary/urban warfare targets with naval fires” under the Time Critical Strike FNC, in spite of the recommendations in the Sea Strike concept quoted in Chapter 1 and

[15]Office of Naval Research. 2001. *Future Naval Capabilities and Required Enabling Capabilities,* Arlington, Va., November 3. Available online at <https://www.onr.navy.mil/sci_tech/futurenaval.htm>.

Box 2.1
Department of the Navy Science and Technology

Future Naval Capabilities

In 1998 the future naval capabilities (FNC) process was instituted to raise the S&T investment focus from individual technology goals to the achievement of future capabilities for naval forces. Input to the FNC process came from the commanders in chief command capability issues (CCIs) and from the Office of the Chief of Naval Operations/Headquarters, U.S. Marine Corps (OPNAV/HQMC) capabilities needs. The OPNAV/HQMC capabilities were organized within the structure of the CCIs and the results were condensed to the level of greatest commonality. The result was the set of 12 FNCs. These were approved by the Department of the Navy S&T Corporate Board.

The Corporate Board also designated the membership of an integrated product team (IPT) to act as a board of directors for each of the FNCs. Each IPT developed the enabling capabilities needed to achieve the future naval capability. While the Corporate Board directed that all of the FNCs were to be treated as having equal priority, it directed that the enabling capabilities be prioritized within each FNC to provide the basis for S&T investment decisions.

For each enabling capability, a program of work on specific technologies was proposed by the IPT, on the basis of ONR's assessment of mature and maturing technologies available and on OPNAV and acquisition executive assessment of transition windows for successfully demonstrated capabilities. Each FNC will follow a business plan that includes execution plans and roadmaps, demonstration milestones, and transition targets and schedules.

The 12 FNCs are (1) Autonomous Operations, (2) Capable Manpower, (3) Electric Ships and Combat Vehicles, (4) Knowledge Superiority and Assurance, (5) Littoral Antisubmarine Warfare, (6) Littoral Combat and Power Projection, (7) Missile Defense, (8) Organic Mine Countermeasures, (9) Platform Protection, (10) Time Critical Strike, (11) Total Ownership Cost Reduction, and (12) Warfighter Protection.

Naval Basic Research

The naval basic research investment is organized primarily around National Naval Responsibilities, to continue to push the state of the art in naval-unique S&T areas and Naval Grand Challenges, which integrate technologies to create new naval capabilities. The complete portfolio of National Naval Responsibilities is still being established, but it currently includes Ocean Acoustics and Underwater Weaponry, with two other areas under active assessment—(1) Hydrodynamics and Naval Architecture and (2) Precision Time and Time Transfer. The Naval Grand Challenges are Naval Battlespace Awareness, Electrical Power Sources for USN and USMC, Naval Materials by Design, and Multifunctional Electronics for Intelligent Naval Sensors.

Marine Corps stated priority needs. Very little investment in non-lethal-weapons-specific areas appears in the current basic research portfolio. The committee also received briefings on Naval Research Laboratory (NRL) programs addressing directed-energy, advanced electronics, and chemical antimateriel techniques that hold promise for application to NLWs to meet naval needs.

2.5 CURRENT NAVY PROGRAMS RELEVANT TO DEVELOPMENT OF NON-LETHAL WEAPONS CAPABILITY

The Navy has had less involvement with NLWs than the other Services have. Standard procedures such as radio warnings, flashing lights, and signal flags or, if necessary, the traditional "shot across the bow" have served as a warning to any potential adversary and have been viewed historically as effective "non-lethal actions" where other vessels are involved. Broader interest in NLWs is emerging, however. They could provide important capabilities in force protection (as discussed in Section 1.2 and Appendix A), strike operations in the littoral environment, and sanctions enforcement. The largest current effort to improve force protection within the Navy is in strengthening and modifying existing systems, tactics, and training to resolve ambiguous situations. Some NLWs unique to the Navy are under consideration and are being tested. Means of delivering both sensors and NLWs using modified surface craft are being pursued. The Navy, unlike the other Services, only recently organized an office in OPNAV N757, and assigned one person exclusive responsibility for following developments in NLWs.

In response to the clearly manifested threat of terrorism involving small boats, swimmers, and small aircraft, the antiterrorism/force protection task force chaired by the Vice Chief of Naval Operations (VCNO) was created by the Secretary of the Navy (SECNAV) in October 2000; follow-on efforts to the work of the task force are expected to be carried out by an AT/FP council. The task force investigated many approaches to assessing a potential threat, such as a surface craft or an underwater attack on a vessel in port, and examined means of countering these threats. Foremost is a heightening of situational awareness through increased alert levels depending on world and regional conditions, or awareness of the likelihood of encounters with unknown watercraft, air vehicles, or underwater threats, and considering host nation port security capabilities. Current operations involve standard procedures for gaining attention and warning an oncoming craft to stay away or to maintain distance. New procedures and systems to strengthen the security of vessels, particularly those at anchor or in port, have been recommended. New tactics and training under development include non-lethal weapons procedures. The availability and use of standard issue items for this purpose are being emphasized. New non-lethal weapons systems are also under consideration.

Table 2.2 presents programs or systems currently in place or under active consideration by the Navy for functions involving non-lethal weapons operations.

Security systems are currently in place for base security. Upgrading the effectiveness of these systems is a natural place to improve security levels. Systems such as badge control (electronic badge/access control system (EBACS)), monitoring of remote facilities by closed-circuit television, guard emplacements, secure communications, and electronic security systems are standard at most military installations. These materials and systems are relatively mature and inexpensive. Additional research will probably yield a relatively small improvement in performance, but improvements in sensors and data fusion should allow a reduction in manpower with a concomitant enhancement of sensing and warning capabilities. The AT/FP task force has made recommendations for naval forces to pursue all of the steps in Table 2.2 as appropriate.

In addition to the systems and methods presented in Table 2.2, programs to test and improve the understanding of non-lethal methods or weapons are outlined in Table 2.3. These programs have a more limited commitment from the Navy.

Activities outlined in Table 2.2 fall principally into the categories of detection and command and control. Funding for these programs and systems is expected to come through current operational funds. Table 2.3 lists activities involving development and testing of concepts associated with non-lethal actions. Plans to continue the programs in Table 2.3 represent future programs associated with non-lethal weapons concepts and systems. Table 2.4 indicates some of the systems that have been proposed but that are not currently funded or under investigation. Not discussed for classification reasons, but showing promise, are HPM concepts applied to stopping small craft.

2.6 CURRENT MARINE CORPS PROGRAMS AND EXPERIENCE RELEVANT TO DEVELOPMENT OF NON-LETHAL WEAPONS CAPABILITY

Of all the Services, the U.S. Marine Corps has the most development and operational experience with NLWs. In addition to being the executive agent for non-lethal weapons for DOD, the Marine Corps has internal responsibility for fielding those systems that accomplish the goals of expeditionary warfare. It has been involved in military operations, such as Restore Hope (1992-1993) and United Shield (1995) in Somalia and Uphold Democracy (1994-1995) in Haiti, in which NLWs were used. Recognizing the high probability of its involvement in similar operations in the future, the Marine Corps has conducted numerous experiments in the use of NLWs for military operations in urban terrain (MOUT) and for crowd control. Before the JNLWD was formed, the Marines began a research, development, and acquisition process that included technology transferred from the Army, commer-

TABLE 2.2 Programs/Systems and Tactics in Use by the Navy or Available Today

Program/Procedure	Description/Comments	Status
Electronic badge/access control system (EBACS)	In use and subject to continual upgrades; this is a portable system, capable of being introduced when a ship enters a port.	At use in some Navy installations; proposals are to consolidate and update.
Electronic security system (ESS)	In many ports and Navy installations, this system can be upgraded with automation and new sensor systems.	In place at Navy installations; proposals are to consolidate and update.
Forward-looking infrared (FLIR)	Mature technology in use today aboard many ships; will be introduced as part of the AT/FP recommendations.	In place on ships; additional systems proposed, especially at harbors.
Regional electronic security system (RESS)	In many ports and Navy installations; this system can be upgraded with automation and new sensor systems.	In place at Navy installations; proposals are to consolidate and update.
Waterside security system (WSS)	*Surface*: Includes IR and radar sensors. *Subsurface*: ANW QX2 sonar able to detect and track swimmers.[a] *Boat barriers*: Waterside barrier system (WBS); Naval Facilities Command has developed a rubber composite floating barrier at $500/linear ft.	ANW QX2 in several ports; commercial model requested.
Crowd abandonment	Tactic used for years by ships at port; i.e., simply sail away from a port where crowds appear threatening.	Standard procedure; used as required.
Fire hose	Fire hose directed at unruly groups of people; serves to dissipate crowds effectively.	On most if not all ships.
Laser dissuader	Various prototype systems have been built; higher-energy lasers capable of causing permanent eye damage; some caution required.	Available for procurement by various vendors (and countries); some probably have already been purchased.
Riot control	Body shields and armor, batons, bullhorns, sirens, high-intensity searchlights, ankle and forearm cuffs, pepper spray, 12-gauge flash bangs, 5.56-mm muzzle-launched ordnance, stun grenade, sting ball grenade, handheld dye marker, water cannons, laser dazzlers.	Readily available from vendors; already on some ships.

[a]Rehn, Karl, and Penny Riggs. In preparation. Non-Lethal Swimmer Neutralization Study Final Report, Applied Research Laboratories, University of Texas at Austin.

TABLE 2.3 Non-Lethal Weapons Programs Being Assessed by the Navy for Force Protection

Program/Procedure	Description/Comments	Status
Area denial to boats and vessels (AD-Boats)	Define operational concepts and requirements and identify technologies to deny an area to boats/vessels.	Future effort by IPT planned (unfunded).
Coastal area protection system (CAPS)	Systems to provide situational awareness and C2; expeditionary concepts intended to include NLWs in future expanded versions of this program.	A program of the Naval Coastal Systems Center currently underway.
Running gear entanglement system (RGES)	Tested and demonstrated effective against most propeller-driven boats (not against jet skis).	Testing continues, especially with Roboski (entry below).
Deployable pursuit boat (DPB)	Vessels that can be used for sensing, warning, delivery of NLWs, as well as delivery of weapons. Roboski, a robotically controlled jet ski, is one; a rubber hull inflatable boat (RHIB) is another.	Roboski is being tested for effectiveness of delivering RGES; other boats are under consideration.
U.S. maritime interdiction operations	Interdiction for purposes of enforcing international sanctions occurs at various times.	This is a tactical concept for ongoing operations.

NOTE: The Navy serves as the lead service to the JNLWD for the AD-Boats and RGES programs.

TABLE 2.4 Unfunded Non-Lethal Weapons Programs Proposed for R&D by the Navy

Program	Type of Program
Small craft disabler	Fire spear into side of vessel near waterline; a fin unfolds, making vessel unsteerable; effective until vessel is repaired.
Sea anchor vessel-stopping system	Attach (possibly by explosive deployment) a net over front end of vessel; system has a small parachute that opens under water, slowing vessel and making steering impossible.
Micro air vehicle	Small UAV, less obtrusive, lower cost, limited functionality.
Ship hull protector	Coatings of materials such as Tuff-core or Lascor, commercially available, that make a hull less susceptible to damage from explosions; could be installed upon ship's arrival at dock.

cially available off-the-shelf items, and some systems from the national laboratories. After the JNLWD was formed, most of the non-lethal weapons R&D was transferred to sponsorship by the JNLWD, with the Marines funded to pursue R&D appropriate to Marine Corps interests and capabilities. These activities are delineated in Tables 2.5 (experiments) and 2.6 (R&D programs) and expanded upon below.

Lessons Learned in Somalia

The experience of the U.S. Marine Corps in Somalia helped shape its requirements for NLWs. The Marines entered Somalia with the U.S. Army 10th Mountain Division in 1993; the mission was to distribute food to the large numbers of civilians who were caught among the warlords competing for power by controlling food supplies and starving the populace. The need to control crowds was anticipated, but the only NLWs available were batons and OC (pepper) spray. Both had marginal effect. As the situation deteriorated and violence escalated, the military came to rely more regularly on lethal force. After a compromised operation to capture a warlord in Mogadishu on October 3, 1993, in which a number of Rangers and Delta Force members were killed by the civilian population, U.S. policy toward Somalia changed. The U.S. troop engagement ended with the withdrawal of U.S. forces and the transfer of the mission to other UN forces.

In 1995, with scant progress made, the UN decided to withdraw all military elements from Somalia. UN command recognized that the extraction of forces could become increasingly dangerous as fewer and fewer troops remained. The United States agreed to deploy a covering force that would assist in the safe evacuation of the UN forces. The mission was assigned to the 13th Marine Expeditionary Unit, Special Operations Capable. The operation was named United Shield.

Under the command of LtGen Anthony Zinni, USMC, the unit trained and planned for the operation. For the first time, the United States announced the incorporation of non-lethal weapons systems into a fielded mission package. The announcement received high-level visibility, including television news reports describing the systems and how they might be employed. NLWs taken on United Shield were riot control agents, low-kinetic-energy rounds, caltrops, the Saber 203 dazzler, the battlefield optical surveillance system (BOSS), and sticky foam.

The availability of these NLWs proved to be an effective deterrence. The BOSS, used in a mode to illuminate areas at night, dissuaded armed people from approaching. Sticky foam was employed as a barrier technology. Many Somalis followed the withdrawing troops, but the NLWs were sufficient to provide a safe distance between the troops and those quickly filling the voids. The mission was successful in that the UN forces completed their withdrawal without a shot being fired.

TABLE 2.5 U.S. Marine Corps Non-Lethal Weapons Experimentation

Project	Experiment Description	Summary Results
Black Hawk Down Study	In December 1998 the Marine Corps Warfighting Laboratory (MCWL) conducted a limited-objective experiment (LOE) regarding the tactics, techniques, and procedures considering two applications of non-lethal directed-energy weapons (DEWs).	Forces using a DEW must ensure that the DEW itself is well protected. If mounted on a vehicle, the DEW should be usable while the vehicle is in motion. A "dazzle" weapon did not appear to be useful in the context of this experiment. The "penetrator DEW" could be a powerful weapon.
Perception Study	Conducted at the Quantico MOUT facility in August 1998. Assessed three progressive non-lethal scenarios representing squadron patrols in an urban area. All the NLWs were concepts (not mature technologies), including a DEW capable of penetrating buildings and incapacitating the occupants, a countersniper system that could pinpoint the direction from which a sniper was shooting, and a non-lethal barrier that would cause discomfort as individuals approached that and eventually incapacitated anyone who attempted to cross it. In addition to the weapons and the squad, "minder" teams were used to recover, sort, and provide medical attention to people incapacitated by the DEW.	
Emerald Express	Conducted in May 1999 at the Marine Corps Research Center; addressed refinements to Humanitarian Assistance and Disaster Relief Assessments and issues and policy implications attendant upon the use of a dazzling laser NLW.	Made recommendations for follow-on efforts, including battlefield optical surveillance system (BOSS), which is a mature technology, in use today aboard many ships; will be introduced as part of the AT/FP recommendations.
Small Unit Leaders Non-Lethal Trainer (SULNT)	Initiated by MCWL October 1996. Simulates peacekeeping scenarios in a three-dimensional virtual environment for teaching small-unit leader decision-making skills. Models civilian crowd behavior and the effects of lethal and non-lethal munitions employed by the U.S. Marine Corps.	Reinforces doctrine, rules of engagement, and other U.S. Marine Corps training.

United States/United Kingdom Non-Lethal/ Urban Operations Wargaming Program	Exercise goals were to identify key policy issues regarding the use of NLWs, identify promising near-term non-lethal systems, identify future NLW requirements, determine employment options across different levels of war and in different scenarios (MOUT), develop concept for employment in combination with other lethal and non-lethal systems; refine NLW "Core Capabilities" (2000).	Key findings: Procure available, "proven" systems for operating forces; identify and work on promising advanced technologies; conduct experimentation and testing, modeling, and simulation; and introduce a limited number of new systems.
Project Lincolnia	Took place in 2000 to 2001. Objective was to determine whether a hypothetical non-lethal directed-energy barrier system (NLDEWS) could reduce casualties in the MOUT environment. The system would have two applications: (1) suppress enemy fire and (2) deny an area—such as a feeding station or evacuation site—to combative crowds.	Significant potential reduction in casualties for both "blue" and "red" forces in scenarios run. Some uncertainty in simulating use of the technology.
Miscellaneous modeling/ exercises	Marine Corps Systems Command non-lethal rigid foam (NLRF) program: MCWL conducted NLRF limited technology assessment (LTA) in October 1997 (Urban Warrior) and LTA in May 2000. MCWL supported phase I (February 1999) and II (November 1999) U.S. Air Force VMADS Program. MCWL supported Center for Emerging Threats and Opportunities (CETO) LTA in January 2001 with a simulated non-lethal VMADS with USMC Operational Command.	Approval at the program definition risk reduction phase: IOC scheduled for FY02.
Miscellaneous programs: mobility denial, portable vehicle-arresting barrier (PVAB), capability sets, hasty barriers	Experimentation with various technologies.	Led to training with capability sets, nail gun for securing facilities, PVAB use, other.

NOTE: Acronyms in this table are spelled out in Appendix E.

TABLE 2.6. Non-Lethal Programs/Systems Explored by the U.S. Marine Corps

Program	Description/Comments	Status
Dragon Drone	MCWL in 1996 initiated work utilizing drones to achieve standoff distances when deploying NLW force. System design and experimentation plan developed by Naval Surface Warfare Center (NSWC) and MCWL; GPS aerial dispensing of various non-lethal payloads. Applications: crowd control, area denial, battlespace shaping.	Proof-of-principle demonstrations.
Light Grenade	FY97/FY98 MCWL tasked to investigate a non-explosive flash grenade. NSWC and MCWL developed a small non-explosive flash grenade with no eye damage potential. COTS flashbulbs and fire mechanism used.	Final report delivered September 1999.
Clear Facilities Concept Exploration Program (CFACCEP)	Surveillance, remote sensing, signature characterization, and biointelligence of a facility to influence, incapacitate, or evacuate personnel utilizing non-lethal weapons technologies.	FY00 funding by USMCSC of multisensory grenade incorporating high-intensity light, acoustic source, and malordorant. FY00 funding of tagging and tracking Small Business Innovation Research (SBIR) programs. Through-wall sensor development by NIJ.
Incapacitation of Personnel Concept Exploration Program (INCAP CEP)	Program CEP that addresses technologies and tactics for both individuals and groups: distract, seize, render unconscious, render incapable of performing an activity, disorient. Exploring: capability sets, DEWs, chemical systems.	Broad area announcement (BAA) for taser system. SBIR: Scientific Applications and Research Associates, Inc., multisensory grenade
OPTION Device	In 2000 MCWL investigated the OPTION weapon-mounted OC delivery device, which integrates with the service weapon and provides a non-lethal alternative to the normal lethal round.	Commercially available.

NOTE: The Marine Corps serves as the lead service to the JNLWD for the CFACCEP and INCAP CEP programs. Acronyms used in this table are spelled out in Appendix E.

As a result of that experience, the Marine Corps led the effort to develop non-lethal weapons capability sets that could provide a significant non-lethal force tool kit for Marine expeditionary forces. These kits have evolved over the past several years to include a variety of kinetic-energy munitions, personnel protective equipment, riot control agents, and vehicle barriers (caltrops and the portable vehicle arresting system). More than 30 of these capability sets are planned for deployment with the U.S. Marine Corps and Army forces.

Military Operations in Urban Terrain

An important issue in conducting military operations in urban terrain is that of countering militia while minimizing injury or death to the non-combatant population that may be present. A number of situations have occurred in recent years in which capabilities to operate in urban areas were operationally tested. The experiences of the Russian Army in Grozny, Chechnya, demonstrated the difficulties that can be encountered when fighting a lesser-equipped force in the complex terrain of urban environments. That situation was comparable to the lessons learned by the Marines assigned the mission to recapture the Citadel in the ancient city of Hue, Vietnam, after the 1968 Tet Offensive by the Vietcong and North Vietnamese Army (NVA) forces. In that battle, under restrictive rules of engagement imposed because of the cultural value of the area, the Marine battalion advanced only three city blocks in 10 days of fighting, while suffering higher than 50 percent casualties. The employment of an NLW finally broke the stalemate. A dispersion of large amounts of CS (tear gas) was used, and the Marines were able to advance through the remainder of the city nearly unopposed. More recent situations in which U.S. forces engaged adversaries in cities include operations in Mogadishu, Somalia; Port-au-Prince, Haiti; and Pristina, Kosovo.

The conduct of MOUT has been and will likely be complicated by restrictions placed on the weapons systems that may be used. Clearing facilities should not destroy buildings, to avoid the problems of reconstruction. Seizing and controlling important infrastructure without destruction of facilities such as communications and municipal utilities (water, power, and so on) will also be important. Moreover, reducing a city to rubble may be counterproductive, as it provides the adversary with many fortified positions from which to fight. In the MOUT challenge the Marines understand that they face many difficult problems, such as (1) defending against militia or insurgents hiding in structures, while not harming innocent residents; (2) clearing buildings of adversary fighting forces while minimizing injury to civilians; and (3) controlling crowds in which it may be necessary to separate militia from civilians used as shields, to stop or dissuade people from rioting, especially in humanitarian relief actions, to disengage from frightened civilians under protection who do not want the force to leave, and/or to circumvent or remove peaceful demonstrators.

The Marine Corps Warfighting Laboratory has conducted a series of experiments with NLWs and surrogate systems since 1998 to improve Marines' preparedness to deal with MOUT situations and, in particular, to assess the added capabilities that NLWs may afford. Some highlights of these experiments (also summarized in Tables 2.5 and 2.6) are as follows:

- In 1998 the MCWL conducted tests of perceptions of NLWs. They also undertook a "Black Hawk Down" exercise based on the events in Mogadishu when two helicopters crashed in what became hostile territory in October 1993; this time the exercise was done with non-lethal weapons options.
- In 1999 the Emerald Express experiment tested the use of light-generating weapons, including the BOSS and smaller dazzlers. Laser dazzlers were found to be effective only in some situations.
- In 2000, the OPTION device for delivery of OC (pepper spray) was explored with results suggesting a useful means of introducing this capability with little inconvenience or cost.
- With assistance from the Potomac Institute, MCWL conducted Project Lincolnia to hypothetically test the use of a directed-energy barrier system in MOUT operations. (At the time of this experiment, the VMADS system was still classified. The test coordinators postulated a system that had similar capabilities without revealing the technical aspects of the millimeter-wave system.) The results of these experiments indicated that systems tested had applicability in the scenarios explored. With VMADS in place, the number of casualties was significantly reduced, while the ability to control crowds was enhanced. An earlier experiment indicated that the presence of a non-lethal directed-energy system must be well protected to be effective, and that it may even require mobility while being used. The general conclusion was that significant operational potential exists for use of directed-energy systems.
- War-gaming operations with the United Kingdom have shown the effectiveness of NLWs in MOUT, including their employment for disaster relief, peacekeeping operations, and countermateriel applications.

These attempts to quantify the effectiveness of NLWs have served to generate enthusiasm for their value among participants.

Embassy and Base Protection

Terrorist attacks against U.S. facilities around the world have increased in recent years and have been effective enough to change policy. In 1983, the Marine barracks in Beirut, Lebanon, was destroyed by a truck bomb. More recent were the 1996 bombing of Khobar Towers in Dhahran, Saudi Arabia, and in 1998 the near-simultaneous attacks on U.S. embassies in Nairobi, Kenya, and Dar es Salaam, Tanzania. All of these attacks resulted in extensive casualties. U.S. embassies in these and many other areas of the world are calling on U.S.

Marine Corps security forces to augment local security in high-threat environments and to respond to crisis situations. In addition to embassy targets, U.S. military personnel themselves have become visible targets for terrorist attacks in many countries. Protection of base facilities and personnel has become a critical function for military security units as well. In most situations, the nature of the location, often surrounded by host nation populace, dictates strict rules of engagement regarding use of force.

NLWs are viewed by the Marine Corps as providing options that may enhance force protection at such sensitive sites. While there may be a need to obtain host country agreement for use of some systems, the following weapons could be available and are being considered for inclusion in base protection packages:

- Dazzling light systems;
- Low-kinetic-impact munitions, such as beanbag rounds (using a 12-gauge shotgun), polyurethane baton rounds, 40-mm crowd dispersal rounds, modular crowd control munitions (MCCMs);
- Vehicle/vessel-stopping systems, such as the portable vehicle arresting barrier and the running gear entanglement systems;
- Riot control agents;
- Flash-bang distraction devices;
- Taser weapons;
- Foam weapons, such as rigid foams, aqueous foams, and slippery materials;
- Caltrops;
- Water cannons; and
- Obscurants.

2.7 OTHER MILITARY OPERATIONAL EXPERIENCE

Besides the experiences in Somalia and Vietnam described in the previous section, others provide insights into the use of NLWs.

United Kingdom

British Army troops arriving in Northern Ireland in August 1969 were poorly prepared to deal with riots and street battles, being equipped only with wooden batons and small shields. After that encounter, an armory of riot and crowd control capabilities was quickly built up: it included tear gas, various impact weapons such as rubber and plastic bullets, and water cannons. Currently, the British Military and the Royal Ulster Constabulary in Northern Ireland use a 37-mm multishot rifle-barrel launcher that fires spin-stabilized, “less-lethal” projectiles. A cylindrical projectile that is very accurate has just been introduced.

Serious injuries with less-lethal projectiles have occurred but are uncommon. Several hundred such injuries have been reported in Northern Ireland since 1970 out of approximately 110,000 rounds fired. Deaths have been rare: 17 in Northern Ireland and only 6 are documented in North America since 1970. Of greater note, no deaths have occurred since 1994, when new baton rounds and launchers were introduced. The British have also used high-intensity sound as a means of riot control in Northern Ireland, but it has met with mixed results and concerns about permanent injury.

Laser-dazzle weapons are in service on British Royal Navy ships to harass enemy aircraft pilots.

Vietnam

In Vietnam, U.S. forces used two classes of NLWs most extensively—herbicides and CS gas.

Herbicides

The chemical 245T was originally used by the British Army in the late 1940s and early 1950s in Malaya against communist insurgents. The objectives were to deny the enemy cover and to destroy suspected guerilla food plantations. In Vietnam, U.S. forces adopted this approach as one of their strategies against the Vietcong, but on a broader scale. In November 1961, Operation Ranch Hand was launched, using U.S. Air Force transport planes specially converted for aerial herbicide spraying and capable of carrying 1,000 gallons per mission. The objectives, similar to those of the British in Malaya, were to deny cover and food. Huge tracts of jungle were sprayed between 1961 and May 1971, when the operation ended. It has been estimated that 64 million liters of herbicide were dispensed on 1.9 million hectares of forest, and 8 million liters were sprayed on 0.3 million hectares of agricultural land.

In all, six different chemicals were used: designated Agents Green, Pink, Purple, White, Blue, and Orange. Agent Orange, which contained small amounts of highly toxic dioxin, is the most notorious. It is estimated that by the end of the campaign, almost 240 pounds (lb) of dioxin had been deposited over Vietnam; comparatively, a few ounces dispersed over New York City would create a serious health hazard with the potential for thousands of deaths.

CS (Tear Gas)

In Vietnam, U.S. forces deployed CS (as well as diphenylamine arsenic chloride (CM) and chloroacetophenone (CN)) for warfighting purposes. CS was introduced into operations in Vietnam to establish barriers and to deny access to the enemy; to drive enemy combatants from deep caves, tunnels, and bunkers when the Vietcong had infiltrated civilian areas; and to support hostage rescue. In many cases, the Vietcong developed simple countermeasures or did not seem to be seriously affected by the CS.

DOD policy for NLWs allows their use in conjunction with lethal systems in order to enhance the latter's effectiveness and efficiency. U.S. use of CS in Vietnam illustrates the point. Large amounts of CS were used not to achieve casualty reductions (a more common use in riot control), but to get the enemy out of places of concealment for non-lethal engagement. In one instance, CS was dispensed from a helicopter, forcing the Vietcong out of a bunker; U.S. Air Force bombers then saturated the area with high explosives and cluster bombs, and ground troops followed to deal with remaining survivors. Such examples, however, can introduce a risk into the acceptance of NLWs for missions other than offensive warfighting—such as peacekeeping for force protection in foreign ports.

Bosnia/Kosovo

When U.S. Army Europe (USAREUR) became engaged in Bosnia, commanders asked for an emergency procurement of non-lethal weapons commercial off-the-shelf (COTS) assets. They acquired many of the same capabilities as those in police departments, developed a theater training strategy (the first in the Army), and secured training from the Marine Detachment at the U.S. Army Military Police School. USAREUR trained approximately 60 soldiers and conducted leader orientations. NLWs were available in Bosnia for more than 2 years but did not have to be used. When the United States then became engaged in Kosovo, USAREUR again requested non-lethal weapons assets. The Army had begun initial development of non-lethal weapons capability sets, which USAREUR received. This time they were put to use.

In April 2000, Task Force (TF) Falcon received a report of contraband weapons in the small village of Sevce, Kosovo. Responding to the report, a detachment of TF Falcon discovered and seized both the weapons and the alleged violator. As the detachment was leaving the scene, a crowd quickly formed and blocked the exit route. TF Falcon took immediate action and sent reinforcements armed with NLWs. The situation deteriorated despite negotiation attempts, and the team on the ground started being bombarded with rocks and large sticks. Several soldiers were injured, none seriously. The on-site commander decided that use of NLWs was appropriate, since the crowd included women and children, some being used as shields. NLWs immediately stripped away the shield, exposing the true agitators, who were also "attacked" with NLWs. The situation was brought to an end. No more injuries were sustained by U.S. soldiers, the crowd dissipated, and U.S. forces returned safely to their base camps. The best testimony to the use of NLWs came from the on-site commander, who stated, "The ability to use non-lethal weapons saved hundreds (possibly more) of lives and prevented me from possibly being involved in the Boston massacre of 2000."[16]

In February 2001, TF Falcon once again faced a tense situation. Soldiers from the task force encountered an illegal roadblock. As they tried to have the obstacle removed, a crowd quickly formed and the soldiers were confronted with a rock-throwing mob. The crowd wedged itself between the soldiers in the main force and their vehicles and blocked any movement. As the situation escalated, the soldiers decided to use NLWs. A first volley scattered the crowd, allowing the soldiers to move toward their vehicles. When it looked as if the crowd would reform, NLWs were employed again, dissipating the crowd and restoring order.

In the incidents just described, both task forces had a full complement of conventional force at their disposal, but they chose to use NLWs instead and successfully accomplished their missions. While not a substitute for lethal force, the option provided an alternative *before* lethal force might have been employed. USAREUR's experience has been fed back to U.S. Army planners for purpose of improving equipment and tactics.

Haiti

With the departure of Colonel Cedras in 1994, the U.S. invasion force converted to a peace support operation called Uphold Democracy. Some troops were provided with NLWs including OC (pepper spray), plastic baton rounds, and beanbag rounds for shotguns. Training for U.S. troops was provided in Haiti. A major obstacle in using NLWs was encountered because of an administrative blunder. Special permission for use of the particular NLWs deployed was required, but it was granted only to the units initially involved in the operation. When units were rotated, the incoming forces found that they could not receive the transfer of NLWs from the departing unit, because authorization for use had not been extended to unit transfers.

Panama/Cuba

A large number of Haitian refugees were detained at the U.S. Naval Base, Guantanamo Bay, Cuba, in 1994. The Haitians became disenchanted with their living conditions and began to riot in December 1994, threatening the guards. Troublemakers were identified and moved to more secure sites in Panama, where the rioting continued. A limited number of NLWs—loudspeakers, clubs, and shields—were available. The use of these systems required that the troops be in close proximity to the rioters, and several rioters were injured.

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[16]LTC James Brown, USA, commander of the air assault and the ground forces involved in fighting the Sevce, Kosovo, riot, personal communication, April 11, 2001.

Garden Plot (Riots in the United States During the Vietnam War)

Because of the riots over opposition to U.S. participation in the Vietnam War in the early 1970s, the military conducted large-scale training of troops in riot control procedures. In general, the troops relied on a show of force and CS to disperse crowds. They retained their standard rifles and were at times armed with live ammunition. While this show of force was effective under some circumstances, the times when it failed, such as in the fatal shootings at Kent State University, led to a national crisis. The weapons available were inadequate to carry out a mission that the military had reluctantly assumed.

2.8 PROGRAMS IN OTHER SERVICES AND AGENCIES

U.S. Army Non-Lethal Weapons Programs

The Army Research Laboratory, Picatinny Arsenal, New Jersey, conducted a program in NLWs from 1991 to 1995. This program—later integrated into the JNLWD—included development efforts in the Bouncing Betty, a 60-mm vehicle-launched non-lethal weapons grenade, and the canister-launched area denial system, as described in Section 2.1. During the program, the Army supplied the Marine Corps with NLWs for Somalia and also fielded NLWs for the Southeast Asia Support Organization's (SASO's) peacekeeping operations.

The Army continues to develop Army-unique NLWs at a modest level. The focus is on developing extended-range NLWs, improving the certainty of results, and developing enhanced effects from these non-lethal weapons. Current activities are undertaken as lead service for the JNLWD and include the development of a 20-mm NLW round for the objective individual combat weapon (OICW). This round is designed to provide an airburst, dispensing liquid aerosols or powders of calmatives, lacrimators, or malodorants; antitraction chemicals; and/or markers to counter personnel or clear facilities. The range of this munition is 5 to 1,000 m. In addition, the Army is developing a frangible 81-mm NLW mortar round with a range of 200 to 2,000 m. Also under investigation is the use of the high-capacity artillery projectile (HICAP) fired round to carry NLWs to a target. The HICAP has a fiber composite case. Its volume is much larger and collateral effects minimal compared with those of a conventional artillery shell. Additional efforts include concepts for dispensing "nanoparticles" to create engine combustion disturbances; an explosively driven high-power microwave generator; and tasers (for electric stun). A malodorant study and methods for dispensing liquid chemicals overhead have received joint program TIP support. Another activity involves development of an aversive audible acoustic system to focus an annoying acoustic wave at hostile personnel. A program to develop a standoff RF engine-stopping system was terminated.

The Army also conducted R&D on mechanical personnel-control systems, such as automatically launched nets. A significant program was conducted at

Edgewood Arsenal, Aberdeen Proving Grounds, Maryland, on a spectrum of chemical systems for antimateriel and antipersonnel NLWs, such as calmatives, lacrimators, and malodorants. Specific details remain classified. The program, after many years of Army R&D investment and the identification of promising technologies, was concluded with adoption of the Chemical Weapons Convention in the early 1990s.

U.S. Air Force Non-Lethal Weapons Programs

Air Force missions that might utilize NLWs include humanitarian relief, non-combatant evacuation, airborne defense, and peacekeeping similar to missions of the Army and the Marine Corps. In addition, the Air Force has the responsibility of maintaining the no-fly zone in Southeast Asia. The principal Air Force non-lethal weapons programs are in human effects at Brooks Air Force Base in San Antonio, Texas, and in directed energy, through the Directed Energy Directorate of the Air Force Research Laboratory (AFRL) at Kirtland Air Force Base, Albuquerque, New Mexico. In fact, the Air Force, under AFRL and JNLWD funding, has developed the leading capabilities among the Services in both non-lethal weapons effects testing and understanding and in directed-energy source development and system susceptibilities. A few examples of Air Force NLW R&D programs are Saber, HALT, and VMADS (discussed in Section 2.1).

The U.S. Coast Guard

The U.S. Coast Guard, having both military and law enforcement responsibilities, is a fundamental component of the national military strategy. During peacetime, the 38,000-member active duty force operates under the Department of Transportation. Missions include maritime interdiction, security operations, counternarcotics operations, humanitarian assistance, migrant interdictions, and fisheries' enforcement. During wartime, as one of the Armed Services of the United States, the Coast Guard serves as part of the U.S. Navy, supporting a full spectrum of conflict in operations related to ports, coastlines, and other shallow waters. In exercising its daily law enforcement responsibilities, such as drug and migrant interdictions, the Coast Guard can and does use U.S. Navy resources and vessels.

The Coast Guard currently uses NLWs in limited circumstances, but it is expanding the complement of weapons to support its maritime law enforcement mission.[17] Most Coast Guard operational scenarios are tactical, with small units operating in close range and in a shipboard environment. The Coast Guard needs

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[17] Jacobs, CAPT Brad, USCG, "U.S. Coast Guard Naval Studies Board Briefing," briefing to the committee on March 7, 2001, U.S. Coast Guard Headquarters Support Command, Washington, D.C.

fixed or man-portable weapons to control non-hostile individuals or groups that are in the water within 30 m and hostile individuals or crowds within 100 m from their vessels, as well as weapons to nullify hostage situations. The Coast Guard also needs to be able to stop vessels when operating from its own cutters, helicopters, and fixed-wing aircraft. It must be able to intercept boats of various speeds and sizes within 100 m without capsizing them and risking serious injury to crew and passengers.

The Coast Guard has proceeded on an evolutionary, but aggressive, path with NLWs, emphasizing careful development of operational concepts and subsequently deploying weapons to a limited extent for operational evaluation. Some dramatic successes resulted when the Coast Guard expanded its current suite of NLWs. It began Operation New Frontier in response to drug runners using go-fast speedboats equipped with counterintelligence radars and operating at night.[18,19] The initiative employed armed helicopters, high-speed boats (versions of rubber hull inflatable boats), and a suite of NLWs that included sting ball grenades with flash bangs and rubber pellets, OC (pepper spray), and 40-mm foam batons fired from an M203 grenade launcher. It also tried an entanglement net deployed from the helicopter, a scenario that was minimally successful because deployment was difficult. In March 2000, the Coast Guard concluded Operation New Frontier and declared it a success. In contrast to its past record of limited apprehension of the go-fasts, the Coast Guard seized all six boats and their crews.

The Coast Guard is enhancing its non-lethal weapons munitions and systems in coordination with the JNLWD. Today its M4/M203 provides both lethal and non-lethal capability in the same weapon and can fire a 40-mm foam baton as well as a sting ball round. While foam is both accurate and effective, the sting ball is adversely affected by the winds at sea. Therefore, a fin-stabilized round for a 12-gauge shotgun is being developed. Both copper slugs and ferret rounds have proven accurate. Riot control gear and large-capacity OC dispensers are promising for migrant interdictions, while individual OC dispensers are useful in one-to-one, close-range engagements. A version of the running gear entanglement system of interest to the Navy uses nets to entangle the propellers of high-speed, small vessels. It requires some adaptation to increase its effectiveness, since launching the nets manually is difficult. A surface-deployed compressed air launcher and an air-deployed canister system are being considered.

A Coast Guard organizational initiative called Project Erickson will establish

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[18]Thompson, Phillip. 2000. "A War Every Day: The Coast Guard's New Frontier in the War on Drugs," *Seapower Magazine,* Volume 44, No. 8, August, pp. 41-44. Available online at <www.navyleague.org/seapower/August 2000/thompson.htm>.

[19]Burgess, Richard R. 1999. "USCG to Go-Fasts: Not So Fast! Coast Guard Scores Aerial Hits Against Drug Runners," *Seapower Magazine,* Volume 42, No. 11, November, p. 52. Available online at <www.navyleague.org/seapower/uscg_to_go.htm>.

a Non-Lethal Weapons Center of Excellence (NLW COE) at Camp Lejeune, North Carolina, along with a Fast Boat Center of Excellence.[20] These COEs will be co-located with the U.S. Coast Guard Port Security Unit Training Detachment. The NLW COE will provide a focal point for the R&D of NLWs and serve as a testing ground for Coast Guard Headquarters, Washington, D.C., and the Research and Development Center, Groton, Connecticut. Its primary function will be to identify, evaluate, and mature tactics, techniques, and procedures for all non-lethal weapons capabilities—and to train personnel in their use. The NLW COE is conducting testing and evaluation of both the 12-gauge munitions and RGES at Camp Lejeune.

The NLW COE also plans to strengthen relationships with the JNLWD, to maximize opportunities offered by non-lethal weapons developments managed by the directorate and other Services and governmental organizations. When new capabilities are required and do not exist within its own Service assets, the Coast Guard looks to the JNLWD, civilian law enforcement agencies, and even international sources to meet the requirement. In turn, the Coast Guard has frequently provided resources and information to the JNLWD. It has supplied substantial information about its operational experience with non-lethal munitions[21] and has led several prototype evaluations. The Coast Guard has also provided detailed maritime scenarios that are relevant to the use of NLWs by naval forces and has supported the directorate's efforts to model and simulate non-lethal weapons capabilities.

Today, Coast Guard units already equipped with NLWs include helicopter interdiction squadrons, over-the-horizon rubber hull inflatable boats, deployable pursuit boats, guardian patrol craft, and fast-rope teams.[22] The intent is to move to year-round full operational capability with NLWs, commensurate with the results of their development and operational evaluations, and to provide appropriate non-lethal tools to all platforms, cutters, small boats, helicopters, port security units, and fixed-wing aircraft. While emphasis has been on the use of NLWs for drug interdiction, the Coast Guard anticipates a continuum of applications across a spectrum of missions.

NLWs in Law Enforcement

Non-lethal weapons technologies and tactics are an integral part of civilian law enforcement. Police are trained to employ a continuum of force, and in the vast majority of police arrests, firearms are not used. Many use-of-force situa-

[20]Stone, Sgt Arthur, USCG. 2001. "Coast Guard Unit Trains for New Role," *The Globe*, Marine Corps Base, Camp Lejeune, N.C., June 14; available online at <www.lejeune.usmc.mil/061401coast.html>.

[21]Several of these munitions form part of the U.S. Army and Marine Corps non-lethal weapons capability sets.

[22]These teams use a vertical insertion technique of fast-roping to board vessels in adverse weather.

tions encountered by police are sudden and in close contact with suspects, requiring immediate, instinctive response. Usually such a situation involves suspect arrest and requires hands-on physical restraint. Other instances may involve standoff situations with the time and opportunity to introduce NLWs. Most non-lethal use of force by the police involves weaponless tactics, such as grabbing and control holds. The use of force during pursuits is a significant issue, with approximately one-quarter of all police vehicle pursuits resulting in collisions; spiked strips appear to be the most effective non-lethal weapons technology readily available.[23] Correctional institutions have similar requirements for the use of non-lethal weapons. In the majority of cases, force is used in prisons and jails where inmates must be removed against their will from their cells. These extractions often result in injury to the inmate and sometimes to the officers.

There are more than 17,000 law enforcement agencies in the United States with a potential need for NLWs. Many of these are small police or sheriff's departments with very limited procurement and training budgets. None of these agencies has R&D funding, although a number of departments have evaluated commercial NLWs for use.[24,25] The central agency supporting R&D of NLWs for law enforcement is the National Institute of Justice (NIJ).

Law Enforcement Experience

Police use of force in the United States occurs infrequently. Each year approximately 1 percent of those persons having direct contact with the police have force threatened or used against them. As pointed out in a 1999 NIJ report, a 1996 study of 7,512 arrests found that police use of force occurred in fewer than 20 percent of arrests—and 80 percent of these instances involved weaponless tactics.[26] Police use of firearms occurred in only 0.2 percent of all arrests. Between these extremes, however, police are increasingly using other NLWs to provide force continuum options. Suspects under the influence of alcohol or drugs are more prone to violence during arrests. OC and tasers have been effective in subduing these individuals.[27,28] NLWs also have been successfully

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[23]Bayless, Kenneth, and Robert Osborne. 1998. "Pursuit Management Task Force Report," Aerospace Corporation, September.

[24]Kimerer, Clark, et al. 2000. "A Less Lethal Options Program for Seattle Police Department: A Report with Recommendations," Force Options Research Group, September.

[25]Meyer, Sgt. Greg. 1992. "Non-Lethal Weapons vs. Conventional Police Tactics: Assessing Injuries and Liabilities," *The Police Chief*, August.

[26]National Institute of Justice and Bureau of Justice. 1999. Executive Summary and Chapter 4, "Measuring the Amount of Force Used By and Against the Policy in Six Jurisdictions," *Use of Force By Police: Overview of National and Local Data*, Research Report No. NCJ176330, U.S. Department of Justice, Washington, D.C., October, pp. vii, 25-44.

[27]Meyer, Sgt. Greg. 1992. "Non-Lethal Weapons vs. Conventional Police Tactics: Assessing Injuries and Liabilities," *The Police Chief,* August.

[28]Bubay, David. 1995. "Oleoresin Capsicum and Pepper Sprays," *Law and Order*, April.

employed in hostage situations, suicide attempts, and other situations in which suspects are threatening force or actions not involving firearms. Riot control with NLWs remains an important police function, as evidenced in the Los Angeles, California, riots in 1992 and more recently in Seattle, Washington, during World Trade Organization meetings.

In the NIJ study referred to above, use of chemical agents (primarily OC) was involved in 1.2 percent of arrests and impact weapons (baton or flashlight) in 0.7 percent. Electrical stun devices were not specifically cited; however, individual police departments have had good success with these devices.[29] Because of its high reported effectiveness, ranging from 85 to 95 percent, OC may be the NLWs of choice in law enforcement today.[30]

Vehicle pursuit by police is one important non-lethal application in need of improved technology and tactics. For the period from 1990 to 1994, 331 persons on average were killed annually in police pursuits, and there were significantly more injuries and property damage. Approximately 20 percent of pursuit fatalities are pedestrians or persons in other vehicles. These statistics have led some departments to enact a no-pursuit policy or to restrict pursuits. Nearly 50 percent of pursuits end in less than 2 minutes, but approximately 50 percent of collisions occur in these short-duration pursuits. This implies that to be most effective, vehicle barriers or disablement devices must be available and deployed early in a pursuit.

Current technology used by more than 90 percent of law enforcement agencies is pre-emplaced barriers or tire deflation systems. However, boxing, barricading, and ramming are also used by many agencies. Existing options for vehicle-disablement weapons must be deployed from police vehicles or helicopters, which is problematic because most police vehicles are manned by a single officer. Technologies that do not affect pursuit vehicles are desirable. Advanced vehicle-disablement technologies of interest to police include advanced mechanical barriers, chemical engine disablement, and electrical disablement. Commercial firms and government laboratories have developed a number of mechanical and electrical direct-injection devices.[31] Disablement devices that require pre-emplacement beyond the tire deflation devices currently available are of limited utility.

National Institute of Justice Program

The National Institute of Justice, which is the R&D arm of the Department of Justice, has three major areas of responsibility: (1) behavioral research, (2) physical sciences research, and (3) dissemination of information to law enforcement

[29] Meyer, Sgt. Greg. 1992. "Non-Lethal Weapons vs. Conventional Police Tactics: Assessing Injuries and Liabilities," *The Police Chief*, August.

[30] Bubay, David. 1995. "Oleoresin Capsicum and Pepper Sprays," *Law and Order*, April.

[31] National Institute of Justice. 1996. "High-Speed Pursuit: New Technologies Around the Corner," National Law Enforcement and Corrections Center, October.

and corrections institutions. The development of non-lethal incapacitation technology is one of 11 research priorities in the physical sciences program. Recent developments have included a sticky shocker, a green laser dazzler, modifications to a ring airfoil projectile developed by the military, a capture net fired from a 37-mm launcher, and an OC projectile that can penetrate window glass before dispensing pepper spray. Past research has investigated sticky foam and aqueous foam materials applications,[32,33] direct-injection devices for disabling vehicles, and the safe use of OC. The total research budget for non-lethal weapons development is modest, and the NIJ program has tended toward leveraging past R&D or modifying existing weapons to improve and extend effectiveness.

The NIJ also participates in several joint programs investigating non-lethal weapons technologies. The NIJ maintains a memorandum of understanding with DOD and the JNLWD to cooperate in non-lethal weapons technology development and evaluation. The NIJ also participates with the interagency technical support working group (TSWG) in sponsoring development of a range of physical security and infrastructure-protection technologies. A notable non-lethal weapons program recently supported by the NIJ and the TSWG was the sticky shocker, developed by Jaycor.[34]

2.9 MAJOR STUDIES OR CONFERENCES SINCE 1996

Papers, conference proceedings, and studies of NLWs have continued unabated since the JNLWD was created. A few of these are highlighted below in chronological order.

Council on Foreign Relations

The creation of the JNLWD has been viewed by some as a direct result of the Council on Foreign Relations study in 1995, described in Section 1.2.[35] In 1998, the CFR conducted a second study of NLWs aimed at a review of what had transpired since an official policy was written and formally adopted and the JNLWD was formed. The principal findings of the study and subsequent actions were as follows:

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[32]Goolsby, T.D. 1994. "Sticky Foam Restraining Effectiveness Human Subject Tests," final report for proposal 96920617, Sandia National Laboratories, Albuquerque, N.M., July 22.

[33]Goolsby, T.D. 1996. "Aqueous Foam Physical Characteristics Testing in Mock Prison Cell," final report for National Institute of Justice project 94-IJ-R-025, Sandia National Laboratories, Albuquerque, N.M. January 19.

[34]A reviewer of this report suggested a taser that includes a substantial round with a soft front end and a couple of darts to shoot into the clothing and convey an electrical shock. The round could contain a capacitor charged before the round is fired.

[35]Weiner, Malcolm H. 1995. *Report of an Independent Task Force on Non-Lethal Technologies: Military Options and Implications,* Council on Foreign Relations, New York.

- The report stated that there was a "high probability of major benefit from a large, urgent investment in non-lethal weapons and technologies." However, the JNLWD budget has not had any substantial increase.
- The CFR also proposed that the JNLWD should "coordinate additional NLW programs within the Services." While coordination by the JNLWD has occurred, no significant independent non-lethal weapons development by the Services has taken place.
- The CFR suggested that cognizance for NLWs should be at the National Security Council (NSC) level in order to provide NLWs a higher level of importance and visibility within the administration. NSC attention to NLWs has been limited.

Non-Lethal Defense Conference IV

In March 2000 the National Defense Industrial Association hosted the Non-Lethal Defense Conference IV (NLD IV) co-sponsored by JNLWD, NIJ, and others. More than 400 people attended—more than any in this series since NLD I, in 1993. NLD IV was the first conference held after the establishment of DOD policy on NLWs, formation of the JNLWD, and line item budgeting for these systems in the defense budget. The most significant change was in the attendance of representatives from major defense industries. Industrial attendees in previous sessions had been largely from small businesses that produced specific NLWs. NLD IV provided an overview of the status of NLWs and research.

United States/United Kingdom War Games

During 2000, a series of non-lethal weapons meetings and war games was conducted jointly with U.S. and United Kingdom units, facilitated by the JNLWD. The intent was to identify policy, requirements, and concepts of operations for NLWs. It was determined that NLWs had applicability across the spectrum, from operations other than war to major theater war. The recommendations were to field proven systems, educate the public about NLWs, develop training programs and establish logistic support, and work on organizational plans for use of NLWs. It appears that some effort has gone toward addressing those recommendations. It is too early to determine how effective the responses will be.

Center for Strategic and International Studies

The Center for Strategic and International Studies (CSIS) conducted a study on non-lethal weapons national policy in 1999.[36] It concluded that NLWs, if

[36] Swett, Charles, and Dan Gouré. 1999. *Non-Lethal Weapons Policy Study,* Final Report, Center for Strategic and International Studies, Washington, D.C., February 5.

technically viable, would be extremely useful as instruments of national policy, and it recommended that the DOD executive agent undertake an expanded S&T program to determine the technical viability of many non-lethal weapons concepts. The report estimated that the level of effort required to address issues identified in the study for the leading technologies would be $100 million per year for 3 years.

Joint Mission Area Analysis Conference

On December 23, 1999, the Commandant of the Marine Corps and executive agent for the joint non-lethal weapons program requested that a joint mission area analysis be conducted. The Joint Requirements Oversight Council (JROC) endorsed the conduct of the NLW JMAA on March 6, 2000. The initial JMAA Warfighters Conference was held in Washington, D.C., on March 27-31, 2000. The JMAA In-Progress Review was held July 18-20, 2000. The final JMAA Conference was held at Headquarters, U.S. Southern Command, October 17-20, 2000. The following findings and conclusions were produced:

- The joint non-lethal weapons program is stable and visionary.
- The joint non-lethal weapons program recognizes the potential of NLWs across the spectrum of conflict and at all levels of war.
- Using a "strategy to task" methodology, the JMAA called out capability deficiencies, identified operational and support tasks needed to meet mission objectives, and provided a master list of non-lethal weapons technologies.
- CINCs and Services JMAA working-group members concurred with respect to three core capabilities and eight subordinate functional areas for NLWs (see Box 2.2).
- JMAA working-group members reviewed and concurred with findings and recommendations of the JMAA and draft mission needs statement.
- JMAA working-group members supported the draft of a capstone requirement document for each non-lethal weapons functional area, as appropriate.

Air Force Scientific Advisory Board

During 1999, the U.S. Air Force charged its Scientific Advisory Board (SAB) with conducting a summer study, titled "Technology Options to Leverage Aerospace Power in Operations Other Than Conventional War,"[37] in which NLWs were one of the areas examined. As part of the study, an extensive survey of technologies that could be employed in current and future systems was under-

[37] Air Force Scientific Advisory Board. 2000. "Technology Options to Leverage Aerospace Power in Operations Other Than Conventional War," Air Force Scientific Advisory Board, SAB-TR-99-01, T. McMahan, chair, February.

Box 2.2
Core Capabilities and Functional Areas for NLWs

- Counterpersonnel
  —Control crowds
  —Incapacitate individual(s) and/or groups
  —Deny area to personnel
  —Clear facilities and structures of personnel
- Countermateriel
  —Deny area to vehicles, vessels, and aircraft
  —Disable/neutralize vehicles, vessels, aircraft, and equipment
- Countercapability
  —Disable/neutralize facilities and systems
  —Deny use of weapons of mass destruction

NOTE: The JNLWD Executive Agent views countercapability as complementary, not core.

taken. It was determined that NLWs did have applicability across the spectrum of conflict and that they would enhance warfighting capability, but that a comprehensive strategy for the Air Force was needed. Non-lethal resources, the study said, should be a part of the campaign planning process as an integrated option. The need for a comprehensive Air Force acquisition strategy to develop, test, and procure NLWs was identified. In addition, the SAB recommended that the Air Force do the following:

- Develop capabilities to assess, in real time, the effects of applied non-lethal means on adversaries for planning and operations;
- Expand the use of non-lethal resources to the full spectrum of conflict during participation in warfighting experiments and exercises; and
- Undertake selected technology initiatives in high-power microwave systems, lasers, and other forms of electronic and information warfare.

3

Principal Findings

Two top-level findings emerged in the deliberations of the Committee for an Assessment of Non-Lethal Weapons Science and Technology. The first observation—not to be obscured by discussion in this chapter in which the committee expresses its concerns—is this: *The progress of the JNLWD, in light of its limited resources and authorities as a joint organization, coupled with the considerable pressure placed on it since its creation in 1996, has been nothing short of remarkable.* The accomplishments of the directorate, highlighted in Section 2.3, are many, and they have had an impact on U.S. tactical warfighting capabilities. That said, the committee does have reservations in several areas about the utility and effectiveness of the directorate continuing in the current direction, as discussed in Section 3.1.

The second observation concerns a broader institutional issue. *The committee finds a wide gap between the rhetoric on the importance of non-lethal weapons as expounded by senior leadership in the unified commands and the U.S. Marine Corps, and the limited attention in planning, assessment, R&D, and acquisition given to NLWs throughout DOD, in general, and the Department of the Navy, in particular.* In spite of the Services' acceptance of responsibility for R&D and testing and evaluation (T&E) for NLWs to meet their own needs (see Box 1.2 in Chapter 1), there have been, at best, limited efforts to assess NLWs as an integral part of the force mix and to plan for their development and acquisition. While the Marine Corps has been the most committed to NLWs and has placed this commitment among its top three or four priorities for enabling Marine Corps warfighting capabilities, even it has been unsuccessful in motivating significant naval R&D. The force protection demands emerging in the aftermath of the attack on the USS *Cole* may prove to be a vehicle for Navy interest, but the committee finds that it is still too early to tell if that experience will result in a more visible program in the Department of the Navy. There are many shortcomings and ample opportunities in non-lethal weapons R&D, systems development, and organizational integration for better-focused and more-robust programs to address existing and emerging needs for the Navy and Marines. These areas are elaborated on in Sections 3.2, 3.3, and 3.4. Summary statements of all of the committee's findings appear at the end of the chapter in Section 3.5.

3.1 JOINT NON-LETHAL WEAPONS DIRECTORATE

When established in 1996, the Joint Non-Lethal Weapons Directorate was specifically chartered to stimulate and coordinate non-lethal weapons requirements. Today, the directorate functions as the DOD focal point for NLWs and is the organization through which the Services coordinate and integrate the development of non-lethal weapons programs.

The directorate has accomplished much since its establishment. With the Services, it accelerated the delivery of non-lethal weapons capability to operational units in the field. It initiated a series of activities to stimulate the requirements process. It began a technology investment program (TIP) to discover new ideas for non-lethal weapons capabilities. It also moved to establish a center of excellence to focus research to characterize the human effects of NLWs. (See Section 2.3.)

The directorate is now poised to transition to a new mode of operation for the future at a crossroads. Having responded to immediate pressures for fielding systems, it has been unable under the current mode of operation to build a robust program for the future within the constraints of its budget and joint nature. There are few major non-lethal weapons capabilities in the acquisition pipelines of the Services; there are few and limited new S&T investments by either the directorate or the Services. Furthermore, there is a significant shortfall in the characterization of the human effects of NLWs. The committee has identified three major findings that indicate a need to alter the future course of the JNLWD:

1. The present JNLWD approach for developing and transitioning non-lethal weapons capabilities to the field cannot be sustained into the future.
2. The JNLWD efforts to stimulate new ideas for non-lethal weapons must be substantially augmented cooperatively with the Services S&T programs.
3. The JNLWD plans and program to address the human and materiel effects of non-lethal weapons through the establishment of a single center of excellence are insufficient and will not meet the need. Without substantial change, the lack of effects characterization will be a "show-stopper" for deploying NLWs to the field.

Each finding is elaborated on in a subsection below.

Transition Challenges

Finding: The present JNLWD approach for developing and transitioning non-lethal capabilities to the field cannot be sustained into the future.

The committee's view is that the directorate's current approach for developing and transitioning non-lethal weapons to the field places the directorate in an unnatural, and potentially unsustainable, position in the normal acquisition process. In that process the acquisition of new weapons systems proceeds through stages, beginning with research to establish the necessary S&T, into concept and technology development, and then proceeding through system development and demonstration before approval for procurement is granted. The "color" of the directorate's money, which is that of exploratory development, places the directorate's role between early S&T and procurement, both of which remain Service roles. Hence, it is not an acquisition organization, nor is it chartered or staffed to perform the role of an S&T organization.

To effect any sort of reasonable end-to-end process in its current approach, the directorate must first rely on the "benevolent" investment of the Service S&T programs to feed its pipeline with new NLW concepts. As noted throughout this report, that pipeline has dried up and the Services have directed their own S&T investments elsewhere. On the other side of the process—i.e., to transition JNLWD development products into acquisition—the directorate has to work through an IPT that first approves a lead Service for execution of the exploratory development project funded by the directorate and then ensures through oversight that at least one Service commits the concept to a properly phased POM cycle for procurement. The fact that any NLWs have been fielded is a credit to the directorate's hard work, but the approach, which has been successful in the past, will become stressed for more capable, more expensive, and more complex NLW systems. For future more complex NLWs the funding needed to mature it through exploratory development will likely be far out of scale with the size of the directorate's total program, much less the size of a single project.

The committee believes that the directorate's current approach will likely be unsustainable for achieving transition of future NLWs into the Services' warfighting capabilities. End-to-end management of development and procurement activities within the Services is the normal process and should be adopted by the DOD for NLWs. The directorate would then be free to invest its full resources in other sorely needed areas such as effects and effectiveness characterization, which are critical for policy, acquisition, and operational decisions and cut across all Service interests and needs.

Stimulating New Ideas for NLWs

Finding: The JNLWD efforts to stimulate new ideas for non-lethal weapons must be substantially augmented cooperatively with the Services S&T programs.

There is a lack of new ideas for NLWs. For all the right reasons, the JNLWD focused in its first few years on mature technologies in order to move non-lethal weapons capabilities into the field quickly. There were two notable exceptions: VMADS and PEP (although VMADS had enjoyed Air Force funding for some years prior to JNLWD investment). Because of very limited funding, there has been little exploration of advanced technologies that come with higher risk and longer time lines for development, but also with potentially higher returns.

The current situation reflects the truism "You get what you pay for" with respect to the non-lethal weapons programs that are now in the pipeline. Few are technologically challenging or militarily exciting. On the other hand, the amount of money invested in non-lethal weapons R&D is currently too small to attract major S&T providers, such as defense contractors, national laboratories, and federally funded research and development centers. Without the probability of substantial sales of successful systems, defense contractors are unwilling or unlikely to use their own internal R&D funds to develop the innovative technologies that can prime the pipeline. If smaller contractors with innovative ideas are identified, substantial financial support will be required at levels not available from currently projected budgets of the JNLWD and the Services to bring them along.

Recognizing the issue, the JNLWD has already engaged in a series of activities to stimulate new ideas and requirements for NLWs. Its technology investment program was specifically initiated to generate new technology concepts through government laboratories, industry, and academia. However, there is still a minimal budget of $500,000 allocated for this program, a sum that is inadequate to attract the interest of the principal R&D institutions referred to here. The committee sees the need for an order-of-magnitude increase in these resources and an expanded and aggressive outreach to find new sources of ideas. Partnerships should be explored cooperatively with government S&T. The Defense Advanced Research Projects Agency (DARPA) and the government laboratories are prime candidates.

The directorate has also undertaken studies and analyses; initiated concept exploration programs; and used war games, modeling and simulation, and experiments to stimulate the requirements process. These activities have been productive. Other, more immediate needs in the non-lethal weapons program have limited the number of such activities, however.

While the JNLWD has mechanisms and programs in place to enable expansion, more are needed. Two CEPs are being used to address high-priority needs, one specifically focused on clearing facilities and the other on incapacitating personnel. More are in order, given the findings of the JMAA. Other examples are experiments and demonstrations, such as advanced concept technology demonstrations. Many opportunities in experiments and demonstrations are focused on operations and missions in which non-lethal weapons applications can play a role—for example, in MOUT and in force protection. The directorate needs to partner in many (not few) joint and Service experiments and in many (not few) ACTDs to evolve concept developments for non-lethal weapons applications. Substantial enhancement of the pace and scope of such activities is essential to move non-lethal weapons capabilities forward.

Programs for Characterization of Effects

Finding: The JNLWD plans and program to address the human and materiel effects of non-lethal weapons through the establishment of a single center of excellence are insufficient and will not meet the need. Without substantial change, the lack of effects characterization will be a "show-stopper" for deploying non-lethal weapons to the field.

The JNLWD is using a variety of mechanisms to address the difficult issues relating to human effects of non-lethal weapons, as described in Section 2.3. Even so, the committee believes that the directorate's approach is unlikely to yield the knowledge base with respect to human effects that is required to support making non-lethal weapons options a pervasive operational reality. Based on the information presented to the committee, it appeared that the JNLWD was mostly leaving characterization of materiel effects to system developers.

The JNLWD has made good use of the Human Effects Advisory Panel (HEAP) since its formation in 1998. The HEAP is an independent panel of experts formed by Pennsylvania State University, under contract with the JNLWD, to provide advice on human effects issues. The committee applauds this move and acknowledges the long-term usefulness of such an expert panel.

The Human Effects Process Action Team was formed in 1999 at the request of the chair of the Joint Non-Lethal Weapons IPT. HEPAT is a group of DOD medical research and acquisition experts assembled to review the characterization process of non-lethal weapons human effects and to recommend changes to ensure full characterization of non-lethal weapons effects. HEPAT made three broad recommendations, which are in various stages of implementation:

- Establish a Human Effects Review Board; HERB was established on October 5, 2000.
- Establish a non-lethal weapons Human Effects Center of Excellence; the HECOE was established in the summer of 2000.
- Adopt a non-lethal weapons risk assessment methodology; the HECOE held a workshop in May 2001 to begin developing a risk assessment framework.

The committee endorses these recommendations, but views them as highly interdependent. Success in the acceptance and use of NLWs hinges on robust effects characterization. HERB is chartered to provide advice and recommendations to program managers on human effects analysis and to provide the milestone decision authority with a judgment on the measure of risk in each program;

both require solid understanding of the effects. In turn, a risk assessment methodology must consider risk to targets, as well as uncertainties based on limitations of human effects models, again requiring understanding of effects. HECOE was envisioned by HEPAT as the centralized resource for conducting health effects analysis. As defined by HEPAT, HECOE would do the following:

- Coordinate human effects modeling and research efforts,
- Ensure that models are peer reviewed and appropriately applied,
- Help weapon designers optimize designs for effects,
- Consult with weapon developers on technological issues,
- Provide input to the concept exploration phase to ensure that human effects are considered,
- Analyze human effects for program managers, and
- Assist in preparation of data packages for use by HERB.

Under its charter, HECOE is not funded to perform fundamental research on human effects. In fact, there is no place in the human effects characterization process, as established, where that research is supported. The committee believes that while the scope of HECOE responsibilities defined by HEPAT is largely appropriate, the implementation falls short in failing to provide a research base and in providing insufficient resources for the program overall.

The JNLWD established HECOE within the Air Force Research Laboratory's Human Effectiveness Directorate at Brooks Air Force Base. The current annual funding for HECOE is less than $1 million, and the JNLWD expects that within 2 years, HECOE will be largely funded by the program managers who require its services. The core technical expertise of HECOE is contributed by the Directed Energy Bioeffects Division of the Human Effectiveness Directorate.

The committee found that HECOE is neither sized nor staffed to cover the diverse range of scientific disciplines required to accomplish its mission as defined by HEPAT. Furthermore, the committee believes that a true center of excellence demands a depth of scientific talent that can be sustained only through active engagement in research.[1] The committee also found insufficient resources dedicated to the creation of knowledge bases and models to capture research

[1]The scope of research is both broad and diverse. A non-lethal weapon is designed to deliver a "dose" (blunt trauma, dazzling light, microwave energy, and so on) at a level below that which would lead to permanent harm to an individual. The threshold at which permanent harm is imparted changes with the individual's age, weight, and so on. An active program to understand thresholds for the "dose" considered for any NLW is essential. Human susceptibility to various forms of directed energy and kinetic energy is largely unknown except for information leading to the definition of occupational exposure and public exposure limits. Without knowledge about mechanisms of additional interaction, it is unlikely that advanced technologies will ever be developed. There is a need to address psychological effects as well as physiological effects. Modeling and simulation represent an interface between the basic science and applications. Contemporary modeling techniques have yet to be developed.

results and lessons learned. While the committee agrees that program managers should be expected to fund system-specific activities, it also believes that substantial shortfalls exist in the basic understanding of human effects and that these shortfalls will not be addressed by the current funding model.

3.2 ADVANCED NON-LETHAL WEAPONS TECHNOLOGIES FOR NAVAL EXPEDITIONARY FORCES

There has been little independent investment in non-lethal weapons S&T by the Department of the Navy since the formation of the JNLWD. In spite of that, a number of areas are well suited to meeting the needs of naval expeditionary forces and to contributing to future naval capabilities. As screened by the committee, the highest-priority S&T elements for naval expeditionary forces are as follows:

- Calmatives and malodorants for controlling crowds and clearing facilities, developed and applied in accordance with U.S. treaty obligations in the Chemical Weapons Convention;
- Directed-energy systems beyond VMADS: HPM for stopping vehicles and enabling distance communications, and solid-state lasers for advanced non-lethal weapons applications;
- Novel and rapidly deployable marine barrier systems; and
- Adaptation of unmanned or remotely piloted platforms and targeting/BDA sensors to non-lethal weapons applications.

A description of the process and criteria for screening, followed by discussion of earlier screened technology areas, is presented below.

Process and Criteria for Screening

A principal outcome of this study is the identification of S&T investment opportunities most applicable to naval expeditionary forces and appropriate for investment by the Office of Naval Research. Attention has also been given to the needs of the U.S. Coast Guard for non-lethal weapons technology, since these can overlap those of the U.S. Navy in selected mission capabilities required.

The wide range of technologies and phenomena that have been proposed for use as NLWs exceeds by far the spectrum of phenomena in use by lethal systems today. This vast array of choices represents a challenge for a rational selection when resource limitations demand that only a few select efforts be chosen for emphasis and funding. The JNLWD has undertaken a complex process to prioritize these choices and to give priority to an appropriate selection of systems that will be funded for development. This committee's focus was on the most promising opportunities for naval S&T programs. Technologies were reviewed individually. In some cases, they were also considered in combination to determine if complementary technologies could provide a broader spectrum of capabilities or synergistic effects. The process steps were as follows:

- There was a review of all material presented to the committee augmented by documents, visits, and information gathered throughout the period of this study. This review allowed the committee to understand mission needs of naval expeditionary forces and to align those with the technologies under consideration. Technologies were screened and entered into the technologies table (Appendix B).
- Each technology, along with associated enabling systems, was discussed, related to mission needs, and grouped by common themes.
- The selection criteria listed in Boxes 1.2 and 1.3 were then applied. This became the basis for selection of the technologies as potential S&T candidates. Further discussion among the committee distilled the potential candidates to the most promising ones highlighted in its findings.

Most important, and emphasized in the committee's review, was the first technical characteristic in Box 1.1—the effectiveness of the technology against the intended target. Effectiveness is a broad criterion; attributes such as predictability, repeatability, and significant effect are incorporated into it. Other factors on the list were used to judge the efficacy of non-lethal weapons technologies, but with no particular priority. These include applicability to one or more of the mission areas of the naval expeditionary forces that could benefit from NLWs. Also required are significant potential bioeffects with the expectation of a broad separation between effectiveness and irreversible injury thresholds. Robustness to countermeasures is considered as well. Rheostatic capability, that is, the ability to "dial an effect" from non-lethal to lethal, for a weapon or system of weapons is desirable, as is selective targeting. Standoff is an important criterion, with desirable delivery ranges of hundreds of meters or more. Delivery systems for non-lethal weapons technologies are considered to achieve these extended deployment ranges. Antimateriel applications also should have the potential to implement repeatable, effective capability to disable vehicles, ships, or other materiel. Finally, the logistical, training, and maintenance support required to field the technology should ideally present little to no added burden to the naval forces using it.

Antipersonnel and Antimateriel Chemicals

Finding: Development of chemicals for non-lethal weapons applications has received little attention since the adoption of the Chemical Weapons Convention. There are, however, riot control, area/facility clearing, and vehicle-stopping situations, as experienced in force protection, peacekeeping, and humanitarian assistance, for which non-lethal weapons chemical options offer considerable advantages over alternatives.

According to U.S. Marine Corps legal interpretation of purposes not prohibited by the Chemical Weapons Convention (CWC) that were presented to the committee, the use of chemical NLWs appears to be allowable for riot control situations and antimateriel applications in certain circumstances. Moreover, chemicals that do not have an inherent toxic effect are apparently allowable. On the requirements side, the committee heard from the U.S. Marine Corps and the JNLWD about the pervasive need—in order to avoid introducing panic in crowds—for crowd control options more benign than those of firing rubber bullets or using OC. The need for and limitations of current vehicle-stopping systems were also evident. In that context, the committee found that calmatives and malodorants for antipersonnel applications and antimateriel vehicle stoppers have high potential as important future NLWs when tested against the criteria listed in Box 1.2. Some of the potential advantages of chemical NLWs are as follows:

- Chemicals offer the theoretical possibility of peacefully incapacitating combatants/agitators, reducing the need for the violence that is frequently associated with many of the current methods. Chemical NLWs could effectively allow a commander to "cool off" a situation, separate the combatants from non-combatants, and then deal with the former appropriately. This may also be true for antimateriel compounds. Many current approaches to stopping a speeding vehicle involve abrupt and often violent actions, with undesired consequences.
- Because chemicals can be tailored to elicit specific human effects through molecular design, they have potential for more precise bioeffects than do currently used NLWs such as blunt munitions.
- Chemicals may be easily dispersed to deliver effects to groups as well as to individuals. For example, a chemical crowd system could be deployed early in tactics, before the crowd has formed a closely packed array, to allow freedom of mobility and harmless escape.

Research in the field of calmatives as NLWs has not advanced for a decade. Previous research had focused on understanding the margin of safety between effective incapacitation and death.

Malodorants, which are not considered toxic chemicals, have a strong potential for controlling crowds, clearing facilities, and area denial. Issues in their effective use include delivery, persistence, and cleanup or neutralization. There has been recent, limited work characterizing the effectiveness of various malodorants. There also appears to be the possibility of combinations of malodorants to address cross-cultural differences in effectiveness.

Almost as important as the nature of the chemicals themselves are the features that "weaponize" them in a manner that maintains both treaty compliance and effectiveness. Little has been done to meet the requirements for more accurate and precise delivery on target with enhanced levels of dispersion. Specific and special methods of delivery are required in a number of naval mission applications. For example, the capability of injecting agents into the air intake of a moving vehicle or boat is an unsolved problem that prevents several promising chemical agents from being considered.

Directed Energy

Finding: Some concepts for radio frequency and laser non-lethal weapons to meet force protection and area denial needs hold considerable promise; others raise serious issues that must be resolved before further significant investment is warranted.

High-Power Microwave and Millimeter-Wave Systems

High-power microwave and millimeter-wave systems offer several promising non-lethal weapons capabilities. The most prominent is the VMADS, for area denial and possibly for crowd control. The VMADs effect—near instantaneous heating of an individual by the RF energy—is well understood empirically, but much remains to be learned about the biological implications of such heating. A major investment will be needed to move beyond the current demonstration stage. Suggestions for shipboard deployment of VMADS to aid in port protection have been made within OPNAV, but such applications will require careful assessment to establish their cost-effectiveness.

The more traditional antimateriel applications for HPM have been sporadically considered for non-lethal weapons applications. Most interesting are applications for stopping engines and disabling electronic equipment. In general, however, the committee reconfirmed a long-standing concern about HPM research—that although HPM has been studied and advocated for a quarter of a century, nearly all of the work consists of demonstrations of an effect, with little to no scientific work to determine the entry mode(s) of the RF energy and the mechanisms of disruption or damage. One notable exception was found. A carefully structured scientific program is underway for some relevant targets. The program is classified and high risk, but if successful, it could substantially increase the efficiency and effectiveness of HPM weapons.

Marx generator technologies represent an area of opportunity that could reduce the size of microwave power generators and make them more practical for expeditionary force operations.

Lasers

The promise of adjustable power levels (i.e., rheostatic capability) makes laser-based NLWs attractive. Current concepts rely on chemical lasers such as DF or COIL, but the disadvantages for expeditionary force applications are many. Chemical lasers require a significant and bulky chemical plant as a part of the system, which also results in a limited "magazine" because of the ability to carry only a fixed quantity of chemicals. Complex logistics and handling, high cost, and unconvincing demonstrations to date further contribute to the unattractiveness of chemical laser systems for non-lethal weapons applications.

PEP and PIKL are cases in point. The DF laser fuel for these concepts is highly caustic and requires special storage and handling. Another concern is the lack of understanding of the physiological effect. As currently envisioned, both systems would deliver enough energy to the target surface (skin) to produce ionized plasma. In laboratory tests using a biosimulant gelatin for skin, the output of PEP was directed toward the target so that the plasma-induced pressure wave could be characterized. In some tests it appeared that the penetration depth was greater than expected. In other experiments dealing with the influence of clothing, it was found that clothing could be burned away by PEP radiation or by the plasma it produced. It was also determined that wet clothing could increase the pressure of the ultrasonic pulse delivered into the body. All of these observations indicate a potential safety hazard and suggest that much more needs to be learned about the physiological effects of these lasers.

Solid-state lasers, however, may offer significant advantages over chemical lasers with respect to environment, safety, logistics, and cost. Unburdened by the chemical storage and handling overhead of a chemical laser, a solid-state laser has the potential to be mounted on a reasonably sized vehicle such as a highly mobile multipurpose wheeled vehicle (HMMWV) and the engine of the vehicle can be its power source, provided the requirements for beam quality, power, and control can be met for non-lethal weapons applications.

Achieving adequate power levels for both tactical and operational applications is the major research challenge. In addition, very short pulse lasers, commonly called femtosecond lasers, have intriguing potential in the materials area. For example, they might be able to cut materials precisely with minimum blowoff and no heating, making this type of laser viable for cutting explosives and toxic materials. Little is know about the human effects from femtosecond exposure to lasers, but experience with longer-pulsed systems suggests that useful but benign effects, such as psychological operations, might be realized.

The committee reviewed some classified ongoing work involving lasers. The committee believes that this work, although highly speculative at the present time, holds considerable promise should it be reliably demonstrated.

Barriers and Entanglements

Finding: Marine entanglement systems have been successfully demonstrated in U.S. Coast Guard programs. Robust systems to meet naval needs, such as stopping go-fast boats or providing perimeter protection in port, need further development.

On the basis of initial successful results with systems such as RGES by the Coast Guard, the committee recognized the usefulness of barriers and entanglements to mitigate fast boat approaches in port and to assist with maritime interdiction. The Coast Guard's needs are not as complex as those of the Navy, however. With the premium on volume and weight on any Navy vessel, predeployed barrier or entanglement systems must be compact and of low weight. As a system for force protection, barriers must integrate rapidly deployed and accurate delivery platforms with the assets for threat identification, warning, and response. Delivery concepts such as Roboski could allow for novel barrier types to be considered, including using the platform itself as a rapidly deployable barrier.

Enablers: Remotely Piloted or Unmanned Vehicles and Sensors

Finding: The emergence of expanded missions for NLWs and more capable—and complex—non-lethal weapons technologies will demand concept development and demonstration for the full system, including platform and sensor integration.

To date, NLWs developed for fielding have been tactical, and they have been deployed with individuals or small units. The relatively greater sophistication and size of VMADS make it the first system demanding a more careful assessment of platform and sensor integration to transform it into a useful operational capability. With the pursuit of any of the technologies discussed in this section, the complexities of the weapon systems will be similar, with corresponding needs for full system integration, along with concept development and demonstration. Few efforts have been made in this direction.[2]

Remotely piloted or unmanned vehicles, especially small UAVs, surface vessels such as the prototype Roboski, and small UUVs, should play an increasingly important role in missions requiring NLWs. These delivery systems are lower cost, provide standoff capability, can carry a variety of sensors and NLWs, are more maneuverable, provide ways of getting sensors and weapons on target, and avoid risking the lives of sailors or Marines. As with their employment for lethal mission support, these vehicles should find use in both sensing and warning, and in delivering NLWs—on land and sea, pierside and outboard, and above and below the surface. This general area enjoys extensive R&D support in DOD for lethal applications. Adapting these vehicles for the delivery of NLWs may be more difficult, however, because of requirements for accuracy for effective non-lethal weapons use. Concept development and analysis are lacking and should be addressed.

[2]A reviewer of this report suggested as an additional possible R&D topic a slow round against stationary distant targets, investigating the possibilities offered by a tiny crude inertial mass and lift devices that would be integrated to control the transverse motion of the round to avoid displacement of the vertical mass.

Just as in lethal engagements, the successful use of NLWs also critically depends on the ability for accurate and timely target identification and localization. Because of the limited range of effect of many NLWs, however, accuracy and timeliness requirements for sensor targeting information may well be more demanding. Sensors must also provide real-time battle damage assessment, that is, feedback on the magnitude of the effect that NLWs have on the target, which is typically more subtle than the detection and assessment of the effects of a conventional explosive device. As with the work on deployment platforms referred to above, adapting work on existing sensors to non-lethal weapons missions is lacking and needed. In addition, the Navy has unique needs for defense against underwater attack, and investigations should be made of the use of NLWs for this purpose.

3.3 NON-LETHAL WEAPONS SYSTEMS DEVELOPMENT

The principal finding in this area is that *the effectiveness of non-lethal weapons is poorly understood in almost every dimension*. This is not surprising in light of the limited scope of JNLWD investment in relatively simple, tactical capabilities and considering the pull-back of individual Service commitments in the past 5 years. Should this situation persist, the development of more capable non-lethal weapons systems in the future will be severely impeded. To mature non-lethal weapons capabilities and gain more widespread acceptance, the systems must be subjected to a robust program of experimentation, a thorough evaluation of training needs, candid assessments of vulnerabilities and countermeasures, and reviews to ensure their consistency with a myriad of evolving logistics and maintenance requirements. In the end, the successful development and deployment of NLWs will depend on many factors, but a thorough understanding of effectiveness will be essential.

The committee's assessment is discussed more completely below. Findings in the specific contributing areas of experimentation and training, logistics and maintenance, and vulnerabilities and countermeasures are also presented.

Effectiveness

Finding: The effectiveness of non-lethal weapons is poorly understood in almost every dimension—a fact that will impede the development of more capable non-lethal weapons systems in the future if not addressed.

Besides the shortcomings in the characterization of human and materiel effects discussed in Section 3.1, there have been very limited efforts in the following areas: quantification of military operational advantages and improvements in capabilities with NLWs, understanding both of U.S. vulnerabilities and of enemy countermeasures to non-lethal weapons use, and development of

CONOPS. In addition, the warfighter must understand and be able to adapt to the inherently variable effects of NLWs—as a specific engagement unfolds, it is essential that the warrior have the ability to obtain and act on immediate feedback to be able to "dial an effect" for re-engagement should that prove necessary. Well-characterized effects and effectiveness are probably the most convincing factor in gaining widespread acceptance and integration of NLWs into warfighting capabilities, yet that area is currently the weakest part of the overall non-lethal weapons program.

Given that the effectiveness of non-lethal weapons options is not well understood, it comes as no surprise that system concepts and assessments are generally immature. Complete systems concepts, including delivery vehicles and sensors for targeting and battle damage assessment, are few. Logistics and maintenance considerations are limited to compatibility with whatever exists. Lessons learned from operational use do not appear to be influencing further development. Fully integrated lethal and non-lethal weapons capabilities remain to be assessed, although such force mixes are essential to implementing effects-based targeting.

There are many dimensions to assessing the effectiveness of a new weapon system. Beyond the technical capabilities of weapons, platforms, and sensors, developers must address the entire range of considerations that go into the development of the system. Table 3.1 contains a list of questions relevant to non-lethal weapons systems. Answers to these questions will provide insight into overall system effectiveness.

It is unrealistic to expect developers of NLWs to have an answer to each of the questions in Table 3.1 early in systems development. However, developers should have a reasonable, affordable plan for obtaining answers as their system concepts mature. Many of the answers to these questions can be obtained through robust experimentation and training, full consideration of logistics and maintenance issues, and candid assessments of vulnerabilities and countermeasures.

Contributing Areas

Finding: Experimentation and training have been limited in scope; logistics and maintenance concepts are immature; and vulnerabilities and countermeasures are not integrally assessed for non-lethal weapons. Each of these areas is important, if not critical, for non-lethal weapons systems development and acceptance by commanders.

Experimentation

A robust experimentation program is an essential element in the development of NLWs. Experiments can highlight new systems' desirable characteristics, benefits, and risks. They encourage thinking about rules of engagement as well as countermeasures and vulnerabilities, and foster the development of concepts of operations. The JNLWD has taken impressive first steps in stimulating experimentation in NLWs with the Marine Corps and joint community and in obtaining lessons learned from related experiments. Many of these activities are discussed in Chapter 2.

The committee believes, however, that these experiments are only the beginning of what must become a more robust experimentation program. To date, many of the experiments have focused heavily on the current generation of tactical NLWs in the capability sets, or more recently, on a VMADS-like system. Over the long run, experiments integrating or geared specifically toward NLWs must be more frequent and pervasive with all the Services and the Joint Forces Command (JFCOM). Experiments should also include a broader and more comprehensive array of scenarios and non-lethal weapons systems, such as antivehicular and antipersonnel non-lethal effects; human response; three-dimensional geographical and structural items such as in urban warfare; robotic systems to detect, target, and engage; tactical advantages such as ballistic protection, speed, and surprise; and systems that support the restoration of infrastructure (such as water, power, and transportation), and provide for the basic needs of a population (food, shelter, and medical aid).

Training

The introduction of new NLWs, such as VMADS, that are considerably more complex than the tactical NLWs in the capability sets requires a substantial increase in the level and sophistication of training. The committee did not see evidence that this level of training was being planned. While specific training needs will vary for each non-lethal weapon system, training will need to address a wide variety of issues, such as the following:

- *Effects*. Users must know the specific effects that they can expect from a weapon. They must understand how the effects can differ with increasing or decreasing distance to the target. They must know if the weapon affects individuals of varying sizes (children, adults), ages (young adults, the elderly) and health or medical conditions differently. They must understand the circumstances under which the system will produce unintended consequences. Because many NLWs are designed to affect human behavior or motivation, users must understand how cultural differences might influence weapon effects.
- *Targeting and battle damage assessment*. Users must understand how to identify, track, and engage targets. They must learn how to assess, with high reliability, whether a system has worked as expected.
- *Tactics*. Users must know when a weapon works best. They should know if its effectiveness can be enhanced or diminished when it is used in combination with other weapons. They must know the importance of surprise, offensive action to achieve decisive results, maneuver, and economy of force. They must

TABLE 3.1 Questions on the Effectiveness of NLWs

System Concept	Target Effects	Other Issues
Is there a solid understanding of the scientific principles behind the observed weapon effects?	If the system is an antipersonnel weapon, is there a solid understanding of *how* it affects the human body?	Is there a clear explanation of why the non-lethal weapon system is truly an improvement over current capabilities, both lethal and non-lethal?
Is there a solid understanding of all the technologies that a field-ready system will require? These could include some or all of the following: sensors for intelligence collection, targeting, and battle damage assessment; robustness to countermeasures; delivery systems (UAV, missile, grenade, etc.); power sources; control equipment; communications equipment; transportation to where the system will be used.	Is there an understanding of *why* the weapon has the human effects observed?	Which organizations are the most appropriate for taking the system through the acquisition process?
Are the technologies available today but need to be integrated? If yes, what are the key integration challenges?	What scientific data on human effects are there in hand? What level of confidence is there in it? How much more research is required on human effects?	Are there strong requirements documents for the system capabilities?
Are technology improvements required? If yes, how long will it take to complete technology development? How much will it cost? Is there a consensus that the improvements are achievable under planned costs and schedules?	What testing will be required to ensure the desired level of confidence about reliable effects and operational suitability? Which organizations will perform developmental and operational tests? Do they have the expertise? Will they need special equipment?	Are there realistic concepts of operations that can be explained easily to a non-expert decision maker?
	How will limits on human subject testing, if any, affect the acquisition of the knowledge needed to understand effects?	Will the system pose unique problems in terms of transportation, maintenance, repair, explosive safety, or other logistics issues?
		Is the system likely to involve toxic or hazardous materials or a health or safety threat to the operators? If yes, what can be done to reduce these risks?

What are the key factors that need to be addressed before the underlying technology can be turned into a true weapon? What needs to be smaller, more powerful, lighter, simpler, safer, etc.? Are there benefits from combining the new technology with others to create synergies? Are there legal or policy restrictions to further research? Development? Testing? Deployment? What should be done about these limits? What is being done to mitigate risks related to cost growth and schedule delays?	Are computer models available to simulate human effects? Are the available models appropriate for the necessary analysis? Are new models needed? If yes, how long will it take and how much will it cost to build them? If the system is an antimateriel weapon, is there a solid understanding of how the weapon affects materiel or equipment of different types? Is there an understanding of the circumstances under which the system is likely to have unintended effects? Are technology investments or highly specialized training of end users needed to reduce the likelihood or consequences of unintended effects?	Can weapon operators confirm that the non-lethal weapon system has worked under likely field conditions? (Some important factors are time, distance, weather, whether it is night or day, ambiguity regarding the intent of vehicles and individuals. The proximity and likelihood of lethal threats may influence the requirements for assessing effectiveness under field conditions.) Are there unusual training requirements that are essential for full effectiveness?

understand how frequently the weapon can be fired and how many engagements are possible before reloading—or its equivalent, such as recharging—is needed. They must understand how to respond to anticipated countermeasures. They must understand the circumstances under which the weapon will not produce the desired effects. Perhaps most importantly, they must understand what to do if the NLW fails to achieve its intended purpose in the expected time frame.

- *Deployment scenarios.* Commanders must understand how to use a weapon in different scenarios. For example, systems that are effective against lightly armed drug smugglers might not work well against heavily armed, well-trained, highly motivated guerilla forces. Effectiveness may vary in urban conflict, peacekeeping, peace enforcement, truce monitoring, disaster relief, humanitarian aid, drug interdiction, and so on.
- *Logistics.* Users need to know what is required to reload and how long a system will be out of operation while reloading is underway. They must know how to maintain and repair the system, how to assess its readiness, how it will be transported, and what is required of the logistics chain to keep it operational.
- *ROE and legal constraints.* Although ROE will vary for each military operation, users must be trained in how a non-lethal weapon system fits into the ROE for their particular situation, including limitations imposed by treaty constraints.

This list of training needs is illustrative, not comprehensive. The introduction of NLWs may create training requirements beyond those for immediate users. For example, the introduction of NLWs that can be fired or launched from a common weapon platform, such as an aircraft, ship, tank, or artillery system, could generate training needs for every organization with responsibility for operating or supporting the platform.

In summary, more complex NLWs will create more complex training requirements. These requirements are likely to be quite challenging for new NLWs. Early, continuing, and creative thinking about training needs is essential for the long-term success of NLW efforts.

Logistics and Maintenance

The logistics and maintenance considerations of most tactical NLWs found in the capability sets have been simple and readily accommodated within existing practices and capabilities. Complex operational-level systems, such as VMADS or some of the laser concepts under development, introduce logistics and maintenance issues that are both unique and possibly burdensome; they must be considered integrally with system development to avoid a "show-stopper" downstream. The current mindset of the NLW community is still at the level of the individual tactical capability set and is not yet acculturated to the perspective that these complex systems demand.

In general, it is important to consider logistics issues during every stage in the weapon development process. Weapon developers can increase operational effectiveness and reduce life-cycle costs by accommodating the varied needs of the logistics community while a system is being developed, rather than afterward. Table 3.2 illustrates logistics questions that should be addressed in the development process.

Vulnerabilities

Because of its charge to study NLWs for U.S. naval expeditionary forces, the committee devoted little attention to NLWs developed or deployed by other nations. The committee's limited exposure to two activities, however, raised concern.

Awareness of foreign NLWs is important for understanding the vulnerabilities of U.S. forces and key infrastructure assets, such as electrical grids, financial networks, and the air traffic control system. Other nations are investigating, developing, fielding, and/or selling NLWs. The committee was briefed on one effort to defeat NLWs and one experiment that highlighted the vulnerability of an important infrastructure asset in the United States. Both of these activities pointed to the current lack of well-thought-out responses to use of NLWs against U.S. forces, and the serious consequences that could result. Proliferation is also a concern. U.S. forces could be vulnerable to NLWs that have proliferated from the United States or foreign nations to enemy nations or non-state actors. Moreover, smart adversaries will develop and exploit non-lethal weapons technologies with or without U.S. efforts in the same technologies if they see an advantage in doing so. In general, NLWs could represent an asymmetric threat to the United States and its allies.

Countermeasures

DOD Directive 3000.3 states that NLWs "must not be easily defeated by enemy countermeasures once known, or if they could, the benefits of a single opportunity to use the weapon in a given context would be so great as to outweigh that disadvantage."

It should be made clear that countermeasures are of two types. The first type, discussed in the directive, includes those countermeasures employed by adversaries to counter U.S. forces' use of NLWs. For these, counter-countermeasures, technical and/or tactical, are needed. The second type includes the countermeasures that could be used by U.S. forces to protect against adversary uses of NLWs. In this latter case, U.S. forces need reaction time for retaliation to the foes' attack and for mitigating options of NLW effects.

Military experience has been that countermeasures, technical and/or operational, appear sooner or later after any system has been put to use. As the

TABLE 3.2 Questions Regarding Logistics Support for Non-Lethal Weapons

Strategic and Tactical Mobility	System Support	Other Issues
How will the system be transported?	Is the system highly reliable? Is it fragile?	Will non-lethal weapons ammunition be managed in accordance with existing policies for explosive safety and suitability for use?
How will supporting infrastructure, such as special equipment for maintenance or repair, spare parts, fuel, and specially trained technicians, be transported?	Will the way that the system is stored and maintained in peacetime ensure that users obtain identical effects every time the system is used in action?	Will new systems have a digital design database to facilitate maintenance and repair?
Is the system compatible with existing transport equipment (ships, cargo aircraft, helicopters, trucks, amphibious landing craft, and so on)?	Is the system easy to maintain? Does it have built-in test capabilities? Can it be maintained and repaired easily in a forward-deployed environment?	Has the system been designed to minimize safety and health risks to U.S. forces?
Can the system be prepositioned on land or at sea?	Can the weapon be fired or launched from existing weapons and platforms, which would reduce the costs associated with supporting a non-lethal unique system?	Can the use of toxic or hazardous materials be reduced to minimize environmental costs?
Are the concepts for system use and support consistent with overall warfighting concepts?	Can fuel or energy requirements be minimized to improve operations and reduce the need for resupply? Does the system require a non-standard fuel?	Are specialized facilities required for storage, testing, training, maintenance, or repair? Is there a shelf life associated with the system or its ancillary equipment and supplies?

directive indicates, by itself the identification of countermeasures should not stop the development or even the considered use, of NLWs. Rather, a thorough evaluation of NLW countermeasures is needed to help weapons designers, highlight needs for more experimentation, and improve tactics and training. Another lesson from experience is that S&T has an important role to play in the development of countermeasures and counter-countermeasures. In the case of NLWs this S&T will involve challenges in both the "hard" and "soft" sciences.

As a simple example, a new system enabling use of different types of NLW at once or in a controlled sequence, governed by an assessment of effectiveness by sensors, knowledge of effects, and psychological and cultural criteria, could provide a degree of counter-countermeasures capability.

3.4 DEPARTMENT OF THE NAVY ORGANIZATIONAL INTEREST IN NON-LETHAL WEAPONS

Finding: U.S. Marine Corps interest and priority regarding non-lethal weapons have been growing since the early 1990s. Navy interest was largely dormant until the USS Cole *incident, but it has been evident since then, growing noticeably throughout the course of this study. Investments in people, dollars, and concept development have not yet caught up with that interest.*

As discussed in Section 2.6, the Marine Corps has had a visible and growing interest in NLWs since the early 1990s. That interest has been reinforced with commitments to development, experimentation, and procurement of NLWs to support tactical mission needs. Needs for more sophisticated operational NLW systems are emerging, but supporting R&D and acquisition are not yet in place. The Navy's interest, however, has lagged behind that of the Marines.

OPNAV Response Prior to Attack on USS *Cole*

The command capability issues provided by the fleet/force to the Chief of Naval Operations, Director, Test and Evaluation and Technology Requirements (CNO N091) in August 2000 reported that non-lethal weapons technologies ranked 19th in the composite roll-up of each command's "Top 10" issues. Box 3.1 lists the needs identified. As noted in Section 2.4, the command capability issues drive the future naval capabilities and accompanying enabling capabilities and supporting technologies.

OPNAV designated an individual to act as the Navy central action officer, Joint Non-Lethal Weapons Programs. The billet currently resides in OPNAV N757, Explosive Ordnance Disposal and Coastal Warfare Branch, Expeditionary Warfare Division. This individual is the focal point for the JNLWD on the breadth of U.S. Navy activities regarding the generation and coordination of non-lethal weapons requirements, the identification of needed technology develop-

Box 3.1
Fleet/Force Non-Lethal Weapons Needs Identified for Command Capability Issues, August 2000

- Counterpersonnel
  - —Clear facilities and structures of personnel
  - —Deny area to personnel; naval force protection (U.S. Naval Forces, Central Command (USNC))
- Protect against swimmer/intruder (Commander, Submarine Force, Atlantic Fleet (CSL))
  - —Control crowds
  - —Stop an individual (combat logistics forces (CLF))
- Countercapability
  - —Disable/neutralize facilities and systems
    - Disable/deny navigation capabilities (USNC)
- Countermateriel
  - —Disable/neutralize equipment or facilities
    - Disable, with pinpoint accuracy, facilities/equipment in the midst of nontargetable facilities/equipment (CLF)
  - —Deny area to vehicles, vessels, and aircraft
    - Stop high-speed vessel/vehicle (CSL, JIATF-E)
    - Stop large-displacement vehicle (USNC, JIATF-W)
    - Close harbor/anchorage (USNC, CSL)
    - Interdict/disrupt mining operations (USNC)
    - Interdict/disrupt submarine operations (USNC)
    - Prevent breaching of controlled spaces (USNC)
    - Selectively control GPS (USNC)

ment, the use and creation of modeling and simulation capabilities, and participation in experiments as well as ongoing and planned acquisitions.

The Naval Surface Warfare Center, Dahlgren Division (NSWCDD) accepted the role as the lead laboratory area in the non-lethal weapons area. ONR provided support to the Joint Mission Area Analysis Conference. The Joint Program Office for Special Technology Countermeasures at NSWCDD accepted the charter for the development of non-lethal weapons countermeasures.

Although the Navy had not formally procured any non-lethal weapons systems prior to the attack on the USS *Cole*, it had undertaken some initial efforts in the acquisition process. It had completed a capstone requirements document on stopping vessels. It had accepted the role as Service lead on the following Joint Non-Lethal Weapons Program efforts: one Pre-Milestone A program for the development of a running gear entanglement system, one CEP to disable vessels, and studies and analysis efforts toward options for underwater and maritime intercept.

OPNAV Response After Attack on USS *Cole*

In response to the attack on the USS *Cole* on October 12, 2000, the Department of the Navy established the Antiterrorism/Force Protection Task Force on October 27, 2000; its activities and recommendations are discussed in Section 2.5. As a part of the AT/FP Task Force effort, technology transition for improved force protection was organized into three efforts: the Immediate Response Program, the Bridge Program, and the Coordinated Acquisition Program. While the latter two are longer term and ongoing, the Immediate Response Program, as its name implies, was given a short time line. On November 9, 2000, the CNO assigned the Office for Naval Operations Other Than War-Technical Center (NOOTW-TC) at NSWCDD to lead the Immediate Response Program. This office undertook an analysis to characterize known and potential asymmetric surface, subsurface, air, and onshore threats to surface vessels in ports and harbors and while transiting restricted waterways to or from ports and harbor areas, to key shore installations (including command centers, aircraft storage, and so on), and to aircraft during approach, takeoff, and landing (outside the continental United States). The office then identified potential technologies, techniques, and/or procedures that might enhance current naval capabilities in the areas of situational awareness (threat detection and classification), defense in depth (threat deterrence and neutralization), and operational risk management, emphasizing commercial off-the-shelf and government off-the-shelf systems. Directions were to include NLWs in the assessment.

On December 13, 2000, NOOTW-TC delivered a "Quicklook" report to the CNO, in which it recognized current force protection capabilities and identified systemic shortfalls. The report recommended near-term enhancements that emphasized the application of technology instead of the increased use of manpower; overt, passive systems for deterrence; active defense systems; *non-lethal weapons capabilities for first response;* and lethal weapons capabilities as a last resort. All candidate technologies could be fielded in 3 to 9 months.

On December 15, 2000, the CNO (N3/N5) organizations directed NOOTW-TC to facilitate an NLW concept demonstration within 60 days. On December 21, 2000, the Commander in Chief, Atlantic Fleet, was briefed on the concept demonstration about to get underway. On December 28, 2000, the Commander, Naval Sea Systems Command, was briefed. On January 2, 2001, the 60-day clock started, with an expected completion date of March 1, 2001. Phase I component demonstrations (AN/APQ-2, water cannon, RGES, detector experiments, live fire gunshoot) were conducted on February 15-23, 2001, at NSWC Dahlgren. On March 1, Phase II, an exercise already underway (DDG-58) was used to demonstrate baseline and enhanced capabilities across three basic scenarios with multiple vignettes. The demonstration results are providing baseline direction for part of the CAPS ACTD (the principal element of the Bridge Program), information for near-term fleet/force decisions, and prioritization of future force protection R&D efforts.

As a result of the success of this demonstration, efforts are underway by OPNAV to establish a more permanent "council" of expertise to address force protection issues and efforts throughout the fleet. Oversight of these efforts will be provided by the CNO AT/FP Council with ad hoc working groups in the areas of personnel, doctrine, training and policy, expeditionary antiterrorism, installations, resources (fragmented and difficult to apply), technology, and intelligence information. Findings and recommendations will be reported periodically to the CNO and fleet staffs.

While aspects of improved naval AT/FP postures include more than NLWs, the value of NLWs beyond their use for tactical self-defense is being recognized more widely in the Navy. It remains for OPNAV to inject NLWs more pervasively into institutional planning, assessments, R&D, and acquisition and to consider offensive roles for NLWs, as recommended in the Sea Strike concept described earlier.

3.5 SUMMARY OF FINDINGS

For ease of reference, the findings presented throughout this chapter are compiled in the following subsections.

On the Joint Non-Lethal Weapons Directorate

The progress of the JNLWD, in light of its limited resources and authority as a joint organization, coupled with the considerable pressure placed on it since its creation in 1996, has been nothing short of remarkable. Looking to the future, however, and assuming that NLWs are to play an integral role in both warfighting and operations other than warfare, the committee believes the following:

- The present JNLWD approach for developing and transitioning non-lethal weapons capabilities to the field cannot be sustained into the future.
- The JNLWD efforts to stimulate new ideas for non-lethal weapons must be substantially augmented cooperatively with the Services S&T programs.
- The JNLWD plans and program to address the human and materiel effects of non-lethal weapons through the establishment of a single center of excellence are insufficient and will not meet the need. Without substantial change, the lack of effects characterization will be a "show-stopper" for non-lethal weapons in the field.

On Commitment

A wide gap exists between the rhetoric on the importance of non-lethal weapons as expounded by senior leadership in the unified commands, fleet commands, and the U.S. Marine Corps, and the limited attention in planning, assessment, R&D, and acquisition given to NLWs throughout DOD, in general, and the Department of the Navy, in particular.

On Shortfalls and Opportunities

R&D

As screened by the committee, the highest-priority S&T elements for naval expeditionary forces are as follows:

- Calmatives and malodorants for controlling crowds and clearing facilities, developed and applied in accordance with U.S. treaty obligations in the Chemical Weapons Convention;
- Directed-energy systems beyond VMADS: HPM for stopping vehicles and enabling distance communications, and solid-state lasers for advanced non-lethal weapons applications;
- Novel and rapidly deployable marine barrier systems; and
- Adaptation of unmanned or remotely piloted platforms and targeting/battle damage assessment sensors to non-lethal weapons applications.

Systems Development

The effectiveness of non-lethal weapons is poorly understood in almost every dimension—a fact that will impede the development of more capable non-lethal weapons systems in the future if not addressed.

Experimentation and training have been limited in scope; logistics and maintenance concepts are immature; and vulnerabilities and countermeasures are not integrally assessed for non-lethal weapons. Each of these areas is important, if not critical, for non-lethal weapons systems development and for acceptance by commanders.

Department of the Navy Organizational Interest

U.S. Marine Corps interest and priority regarding non-lethal weapons have been growing since the early 1990s, although the Marine Corps and the JNLWD have not been successful in motivating naval-unique R&D investments in non-lethal weapons. Navy interest was largely dormant until the USS *Cole* incident, but it has been evident since then, growing noticeably throughout the course of this study. Investments in people, dollars, and concept development have not yet caught up with that interest.

4

Conclusions

4.1 JOINT NON-LETHAL WEAPONS DIRECTORATE

The case for non-lethal weapons appears to be strong and getting stronger. For NLWs to achieve their potential as an integral option within the warfighters' arsenal, however, their development must be executed through the Services' Title X responsibilities, and their operational employment must be effectively supported by policy and doctrine. Today, however, NLWs are at best a specialty item, most often linked to limited roles in peacekeeping or force protection rather than being viewed for traditional warfighting missions. Operational experiences during the past decade have increased awareness of the military usefulness of non-lethal weapons options, but advocacy within the Services, with the exception of the Marine Corps, remains weak.

In many respects, employment of NLWs represents uncharted territory for DOD. The effects of most NLWs are not well understood, leaving rules of engagement not clearly defined. While categorized as "non-lethal," some weapons may cause irreversible health effects or may, in fact, be lethal under certain conditions. For some classes of NLWs, the human effects may be invisible in the absence of a medical examination, may appear only after considerable time has elapsed, may be exacerbated by environmental factors or individual susceptibilities, and may include psychological as well as physiological or biomechanical effects. The problem is compounded by the diverse range of phenomenologies that could provide non-lethal weapons options and by the use of the term "non-lethal" to encompass weapons that achieve materiel effects as well as weapons that target humans.

The JNLWD has made visible progress in a relatively short time in its role as advocate and coordinator for non-lethal weapons programs within DOD. NLWs are unlikely to survive the Services' requirements processes in the absence of strong advocacy, and non-lethal weapons options are unlikely to be operationally employed in the absence of a far better understanding of both mission effectiveness and potential health or materiel effects. The committee therefore sees a continued need for the JNLWD to focus and facilitate transformation from the present to a time when non-lethal weapons options are fully normalized within DOD's development, acquisition, and operational processes.

It is the committee's judgment that the directorate could more effectively speed the normalization of non-lethal weapons options by focusing its limited resources on a few high-priority problem areas. Accordingly, the committee came to these conclusions:

- Without compelling new ideas, NLWs will remain a specialty item in the warfighter's tool kit and will never become the effective element of warfighting that countless studies and limited operational experience have affirmed NLWs can be.
- Without a different process for introducing new non-lethal weapons capabilities—one more integrated into the normal Service development and acquisition cycle—the current scope of the program offers only a low probability of moving even the best ideas to the field in the future.
- Without a much stronger overall program to understand and characterize the effects and effectiveness of non-lethal weapons, commanders will remain reluctant to request or employ them.
- Without concepts for the use of non-lethal weapons, developers will not be successful in focusing ideas and programs.

The JNLWD should now focus on the following: stimulating new non-lethal weapons concepts through exploratory investment; stimulating the requirements process through lessons learned from real-world uses, gaming, and experimentation; and building the intellectual underpinnings to give commanders the confidence that NLWs provide effective and viable options for specific missions. The committee believes that once the Services recognize the value of non-lethal weapons options and commanders gain confidence in their usefulness, this family of weapons will compete favorably within the requirements process. At that stage NLWs would become part of the Services' culture, hence, the Services would become the advocates, and the responsibility for the assessment of the effectiveness and effects of proposed non-lethal weapons systems would transition to an appropriately augmented test and evaluation community.[1]

[1]The committee observed that the Joint Combat Identification Office (JCIDO) provided a somewhat parallel precedent for a limited-life joint organization. JCIDO was established in 1993 to deconflict and coordinate technology development and to build a repository of signatures to facilitate non-cooperative target recognition. After successfully rationalizing the activities and establishing ownership within the Services and joint staff, JCIDO was disbanded in the late 1990s. The committee estimates that the execution of a strong and focused program by the JNLWD during the next decade could achieve comparable success.

4.2 NON-LETHAL WEAPONS AND NAVAL EXPEDITIONARY FORCES

The committee believes that the mission needs for NLWs to support naval expeditionary forces are clear and compelling. Force protection challenges and shortfalls alone should be motivating the Navy to a higher level of commitment to the development and acquisition of promising non-lethal weapons technologies and systems. Implementation of the Sea Strike concept makes the case for the Navy even more compelling. The Marines have sufficient and successful tactical experience with NLWs to motivate interest in more capable systems to support operational as well as tactical needs.

As mission motivations for NLWs grow, especially for more sophisticated systems, new non-lethal weapons programs cannot be supported within the constraints of the JNLWD's budget and scope of responsibilities. At the same time, these new programs are faced with inserting themselves into an exhaustive list of already identified and established Navy and Marine programs. Successful integration of NLWs into naval expeditionary forces will take some deliberate institutional changes within the Department of the Navy. Planning and assessment to consider NLWs integrally with other force improvement options should be the rule rather than the exception within the Office of the Chief of Naval Operations for Warfare Requirements and Programs (N7). Future naval capabilities integrated product teams should be addressing NLWs more pervasively and should be identifying key enabling capabilities. R&D investments by ONR are needed to develop more advanced and capable NLWs, tailored to naval needs and environments. In short, both the Navy and the Marine Corps should show Service leadership by preparing for the needed shift in focus of the JNLWD, as noted above, and accepting their own end-to-end responsibilities for researching, developing, acquiring, and fielding non-lethal weapons systems to meet their unique needs.

5

Recommendations

The committee's recommendations build on its findings and conclusions, calling for specific actions or activities by the Joint Non-Lethal Weapons Directorate, the U.S. Navy and/or the U.S. Marine Corps, and the Office of Naval Research. In making these recommendations, the committee is assuming that all parties acknowledge the potential of non-lethal weapons for supporting a wide range of operations envisioned for naval expeditionary forces. The recommendations have been carefully developed to focus primarily on shifts in emphasis within each of the organizations noted, as opposed to calling for the commitment of more resources, at least at this time.

5.1 JOINT NON-LETHAL WEAPONS DIRECTORATE

Recommendation: As the Department of Defense's focal point for non-lethal weapons, the Joint Non-Lethal Weapons Directorate should focus its resources on stimulating and exploring new ideas, and on strengthening the DOD's ability to characterize the effects and effectiveness of non-lethal weapons.

The committee believes that the future impact of the JNLWD will be considerably enhanced if the JNLWD's mission space is narrowed to two core missions and the investment in each is significantly increased. The core missions recommended for the JNLWD are to speed transformation of NLWs from specialty status to that of fully integrated warfighting options through strong advocacy and to increase confidence in non-lethal weapons options by expanding DOD's understanding of the effects of NLWs on humans and materiel. These are not new missions for the JNLWD, but success, as envisioned by the committee, will require significantly stronger programs in each area.

Implicit in this recommendation is the transition of non-lethal weapons system development and acquisition responsibilities to the Services. The committee believes this is the appropriate next step toward full acceptance by the Services, when NLWs will have become a valued option for the warfighter and the JNLWD will no longer be needed to advocate their development and operational use. Institutionalizing this recommendation, which would result in changes in roles and responsibilities among the JNLWD and the Services, will require a revision to the Joint Service Memorandum of Agreement on Non-Lethal Weapons. As such, OSD/JCS, the JNLWD, and the Services will need to agree to the changes proposed above. Moreover, the assumption of end-to-end development and acquisition responsibilities by each Service will require their own commitment of resources (funding and personnel) to establish their in-house programs.

In its role as DOD focal point for non-lethal weapons, the JNLWD should aggressively stimulate and explore new ideas. The committee recommends that the JNLWD build a significantly more robust outreach and exploratory investment program, to include partnerships with DARPA, U.S. government laboratories and law enforcement communities, and allies, as well as frequent interactions with the industrial base in which the directorate reiterates its requirements for potential developers. Sponsorship of and/or active participation in conferences, publications, and meetings should be a priority. During the transition of full RDA responsibilities to the Services, the JNLWD should help stimulate individual Service investments through cofunding of mutually interesting concepts or should be the sole investor, as needed, to advance novel ideas. The directorate should also seek out groups such as the JASONs[1] in helping to identify new concepts for NLWs. The JNLWD should build a diverse collection of operational scenarios in which NLWs could provide viable options to a commander, and it should communicate these scenarios to various audiences in an effort to stimulate new ideas in which it could then invest exploratory funding.

The JNLWD should also seek to stimulate the Services' requirements process by advocating and funding functional concept assessment and ongoing experimentation. The directorate should identify partners within the Services as early as possible and should nurture such partnerships through cofunding of experimentation. Non-lethal weapons concepts should be explored through wargaming, ACTDs (e.g., MOUT and protection of ships in port), and joint and Service experimentation (e.g., fleet battle experiments, expeditionary force experiments, advanced warfighting experiments). The JNLWD should maintain the joint mission area analysis and should increase its investment in systems analyses, with particular focus on functional concept development (e.g., area denial, crowd control). As new non-lethal weapons systems concepts emerge,

[1]JASON is a rotating group of the nation's foremost scientists who have, since the late 1950s, devoted extensive time and energy to problems of national security.

the JNLWD should partner with one or more of the Services to share in the cost of the system-specific concept exploration program. This partnership sets the stage for subsequent Service ownership—and funding—of the development and acquisition processes.

The committee believes that characterization of the effects of NLWs remains the make-or-break item that will determine their acceptance by policy-makers and subsequent operational employment by commanders. Achieving a robust understanding of the full range of physiological, biomechanical, and psychological effects on humans will require a substantial and sustained investment. The challenge is compounded by the diverse range of phenomenologies for NLWs, as well as by the fact that materiel effects must also be characterized. The committee therefore recommends that effects characterization be the second core mission for the JNLWD and that the program be significantly expanded in this area.

The ultimate goal of effects characterization is to build the necessary knowledge base and modeling capabilities to position the JNLWD to provide a "seal of approval" for specific non-lethal weapons systems. The seal of approval would indicate that the effects are well understood and documented, so that rules of engagement could be clearly defined. As the ability to characterize effects matures, the committee envisions that this "seal of approval" process, initially established and implemented by the JNLWD, will migrate to an appropriately augmented test and evaluation community.

The committee recommends that the center-of-excellence construct continue to be used by the JNLWD to build the knowledge base and models required for effects characterization. Because of the diverse scientific disciplines involved, however, the committee believes that a more viable approach is to establish multiple COEs, each focused on a specific non-lethal weapon effect and centered on the requisite base of scientific expertise. The committee estimates that about five or six COEs (e.g., for blunt trauma, directed energy, chemical effects, and so on) would be needed to cover the range of human effects, but it recommends that the JNLWD determine the number and optimal location of each COE after a more comprehensive assessment and consultation with the Human Effects Advisory Panel. The committee also recommends that one or more COEs be devoted to supporting the characterization of materiel effects. Specific responsibilities of individual COEs are defined in the next recommendation, in Section 5.2. The JNLWD will play a crucial role in establishing and managing the COEs and in ensuring that their individual contributions are effectively integrated to build characterization capabilities for the desired system-level effects. It is envisioned, however, that the need for oversight by the JNLWD will eventually be replaced by the Services' direct engagement with the COEs under the sponsorship of the operational test and evaluation community.

The committee recommends that the JNLWD take immediate steps to strengthen the two core missions described above while gradually transitioning their development and acquisition programs to the Services. Developmental programs should be transferred at a mutually agreed time, but within the next 3 years. Seamless transition of these programs is vital to their continued advancement.

During FY02, the JNLWD should continue its advocacy efforts and should build expanded out-year programs to support exploratory investments and increased experimentation. The directorate should also determine which COEs are required to support the JNLWD's core mission of effects characterization, develop a baseline reflecting the current state of understanding in each area, identify centers of technical expertise, and initiate negotiations to establish COEs. During FY03, the JNLWD should have agreements in place with the COEs and should task them to begin building knowledge bases, catalog existing effects models, and define research agendas. In FY04, the JNLWD should substantially ramp up its investment in effects-related research.

The committee notes that the JNLWD will require at least its current level of funding to adequately support the two core missions at the scope described above. If the directorate's budget is reduced as responsibilities for system development and acquisition transition to the Services, it is unlikely that NLWs will achieve their envisioned potential as either an option for warfighting or for operations other than warfare. Of equal importance is the staffing of the directorate to best fit this new advocacy and effects-based focus. Most of the talent in the directorate today is well suited to its current roles in development and transition to acquisition. The future focus of the directorate will require expertise in the areas of modeling and simulation, biological and materiel effects, and, to a limited extent, science and technology for the assessment of new concepts.

5.2 CENTERS OF EXCELLENCE

Recommendation: The Joint Non-Lethal Weapons Directorate should establish and sustain human and materiel effects-focused centers of excellence to support a "seal of approval" process for non-lethal weapons systems.

The ultimate goal of a center of excellence is to build and maintain the intellectual foundation required to characterize the effects of non-lethal weapons technologies to the extent that policy makers and commanders can be confident of NLWs' viability in operational engagements. A robust understanding of effects is key to establishing policy, rules of engagement, and doctrine for NLWs. Without such understanding, non-lethal weapons options will not be fully exploited. Essential features for a center of excellence are these:

- Key personnel whose relevant technical expertise is widely recognized among their professional colleagues, whose reputations attract top talent to the COE, and whose credibility builds confidence in NLWs among policy makers and commanders;
- Laboratories and computational facilities necessary to support ongoing research, experimentation, and testing to advance the state of the art continually; and

• Synergistic partnerships with other pockets of relevant technical expertise so that the COE fully leverages work done elsewhere.

Each COE should be established with an entity having the features described above, regardless of whether it is affiliated with a government laboratory, an academic institution, or private industry. If the organization is outside the government, it is imperative that the parent organization (and key personnel) be willing to commit to a long-term relationship in support of DOD's national security mission. The committee recommends that bidirectional rotational assignments (COE personnel on temporary assignment to the JNLWD and JNLWD personnel temporarily assigned to the COE) be used to help build mutual understanding and to strengthen the working relationship.

Responsibilities of a center of excellence include these:

• Continual advancement of the state of the art in understanding effects through maintenance and execution of a focused research agenda; research may be accomplished by partners as well as by COE personnel;
• Provision of grants to medical schools and teaching hospitals for supportive research;
• Support for exploration of non-lethal weapons concepts through maintenance of a knowledge base that captures and catalogs all relevant research together with lessons learned from prior experimentation; meta-data and databases must be readily accessible and easily searchable by JNLWD and Services personnel;
• Support for experimentation with non-lethal weapons technologies through the development, validation, integration, and maintenance of models that enable effects characterization; models must be available throughout DOD; and
• Support for the seal-of-approval process for NLWs by defining effects test regimes—and, if necessary, executing tests—for developmental systems.

Because the current baseline of understanding of effects varies considerably by discipline, the size and character of each COE would also vary. Once the JNLWD has identified the desired location for a COE, the program and milestones must be established to fulfill the responsibilities delineated above. Each COE must be funded initially by the JNLWD at a sustained "foundation" level for executing core responsibilities, which include development and maintenance of the knowledge base, development of effects models, and definition of the research agenda. Service interest and cooperative funding should be developed at this initial stage. While specific amounts of funding would vary because of the relative maturity of understanding of the specific effects, the committee estimates that each COE would require a minimum of $1.5 million per year to support these core responsibilities.

Funding for the research agenda is not included in this foundation level, nor is funding to accomplish the integration and accreditation of models needed to support the seal-of-approval process. The JNLWD must develop a prioritized research agenda that integrates the agendas from the individual COEs, and it must then augment COE funding to support research priorities. After the initial stage, Service funding should bear the majority of the COE funding; however, the JNLWD must also augment COE funding to support integration and accreditation of effects models with DOD program managers funding system-specific models and tests.

The committee noted that examples of highly productive COEs exist in other programs and agencies, and it recommends that the JNLWD visit several to identify relevant best practices to help strengthen the directorate's own COE management processes.

5.3 SCIENCE AND TECHNOLOGY

Recommendation: In cooperation with the JNLWD and other Services, ONR should invest in a richer portfolio of NLW-specific R&D activities in the areas of chemicals; directed energy; barriers and entanglements; underwater defensive systems; and platform, sensor, and command-and-control system enablers.

While the committee identified a number of activities within ONR's portfolio and elsewhere that could contribute to more capable non-lethal weapons systems, it found little that was specifically aimed at NLWs, especially in the areas identified by the committee as most important for meeting the needs of naval expeditionary forces. At the same time, the committee found activities that it recommends that the JNLWD stop or redirect.

Chemicals

Chemical non-lethal weapons development has all but stopped since the adoption of the Chemical Weapons Convention, yet there are compelling applications in engine stopping and crowd control that cannot be achieved by other means. The Army's laboratories at Edgewood Chemical and Biological Command (ECBC) remain the center of expertise in development, characterization, and testing of chemicals for military uses. ECBC's charter does not extend to "weaponizing" such chemicals, since its principal focus is on developing countermeasures and defenses to adversaries' use of chemical and biological weapons. It is in this area that ONR and its research community can play a strong role—namely, in developing the non-lethal weapon system to include effective means of stabilization and encapsulation, delivery and dispersion, and real-time sensing and control to ensure that employment of the weapon remains within safe limits and that the desired effects are achieved. A partnership between ECBC and ONR could be very powerful for developing viable chemical antipersonnel NLWs well within the bounds of U.S. treaty obligations. That partnership should also be extended to the development of antimateriel NLWs. ECBC has a history in that area, as well. NRL has given some consideration to the development of engine cloggers, estimating a cost of about $5 million over 5 years.[2]

Because of the political sensitivities associated with antipersonnel chemical NLWs, the elements of the research program must be carefully chosen and structured to comply not only with national and international law and treaties, but also with national policy. The committee recommends the following steps:

1. Identify opportunities for potential applications of malodorants. The use of malodorants has potential for crowd control, facilities clearing, and area denial. Cultural variations in susceptibilities, health effects, and behavioral responses require study. Concern is expressed about the persistence of malodorants, especially if U.S. forces need to occupy an area immediately after use. Thus, accompanying neutralization or controlled decay of malodorants will also have to be studied. Analogous to techniques of chemical switching commonly used in the biochemical and chemical imaging fields, it may be possible to synthesize malodorants that can have their odor functionality chemically switched off.

2. Increase research in the field of human response to calmatives. Calmatives have potential as NLWs in many types of missions where calming of individuals or crowds is needed. As discussed in Section 2.1, prior research had been aimed at understanding margins of safety between loss of consciousness and death, whereas in crowd and riot control situations, the goal is to ensure a wide margin of safety between quieting and unconsciousness. The human effects of these compounds and their safety must have thorough evaluation under conditions simulating their mission uses.

3. Target efforts to develop chemical delivery systems. Although a number of promising chemical non-lethal weapons technologies exist, most of them lack a suitable delivery system. Few reliable, low-risk, and low-cost methods exist for delivering and dispensing chemical NLWs precisely and accurately. This capability is important for delivering antimateriel NLWs to the air intake of an engine, for example, where novel platforms such as robotic or micro-UAVs may be the only solution. It becomes critical in the delivery of calmatives, where proper doses must be achieved. Sensor systems may be able to enhance the potential for many chemical NLWs if they can help achieve accurate delivery on target at the proper dose levels. Special packaging techniques such as microencapsulation should be explored because they may be useful in creating new, more deliverable forms of chemical NLWs.

Directed Energy

The recommended actions for directed-energy NLWs touch numerous organizations because of the various stages of development around the technologies

[2]Mowrey, Robert, "Material Failure/Additives to Fluids," briefing to the committee on March 7, 2000, Naval Research Laboratory, Washington, D.C.

assessed: (1) VMADS adapted to naval force protection needs should be assessed by the Office of the Chief of Naval Operations, Warfare Integration and Assessment Division (N70) and/or the Assessment Division (N81); (2) ONR, through NRL, should complete work started on high-power microwave for non-lethal weapons applications and transition it to development and acquisition if it is promising; and (3) the JNLWD should reassess its commitment to ATL and PEP.

1. VMADS, adapted to naval force protection needs, should be assessed by N70 and/or N81. VMADS has emerged as a candidate for ship-based port protection. The committee urges N70, in partnership with N81, to undertake a careful assessment of the potential cost-effectiveness of VMADS, given the number of unknowns that still exist in weaponizing the concept. The current version of the VMADS prototype has long warm-up times and its mobility is limited. In addition, a more thorough assessment of its health effects, its effectiveness if used against uncooperative crowds, and the ease with which it might be countered is essential before a commitment to development and acquisition should be made.

2. ONR, through the Naval Research Laboratory, should complete work started on the high-power microwave for non-lethal weapons applications and transition it to development and acquisition if it is promising. Excellent work is underway at NRL in coming to understand the mechanisms of interaction of HPM with important targets for defensive purposes. Although the uses of HPM have been studied for some time, nearly all of the work has been demonstrations of an effect, with little effort to determine the mechanisms of disruption or damage. A careful analysis of these disruption mechanisms will lead to improvements and robustness in HPM systems of interest for naval non-lethal weapons applications. The NRL program is structured in a more scientific and systematic manner than any the committee has seen, and it shows considerable promise for producing results that will either clearly pave the way for non-lethal weapon development or stop further investment.

3. The JNLWD should reassess its commitment to ATL and PEP. Although there is the potential for aircraft-based high-energy laser (HEL) systems to deliver rheostatically controlled fluence to precisely selected targets, many of the enabling technologies lack maturity. One such area is precision pointing. Techniques and algorithms that can operate in the presence of atmospheric turbulence and aircraft vibration have not been identified. Another technology area of concern is the laser system itself. Currently proposed systems are based on chemical laser technology such as COIL. This choice of laser system suffers limitations of high atmospheric absorption and logistic difficulties associated with its chemical fuels. The committee recommends that research and development of these systems be conducted in existing HEL weapons programs, such as the airborne laser (ABL) or the theater high-energy laser (THEL), within the Air Force research community. As the enabling technologies mature, pursuit of them as non-lethal weapons applications may be appropriate, but in and of itself, ATL does not yet offer a convincing case as a cost-effective NLW system.

The development of PEP is at a very early stage. It requires critical analysis and review of both technology and human effects before its development proceeds. The committee urges the JNLWD to undertake an independent review across the entire scope of the PEP program to better understand the required and prioritized investment approach, if indeed the review board endorses the development of PEP for non-lethal weapons purposes.

While chemical lasers do not yet hold much promise for non-lethal weapons applications, solid-state lasers may. Little effort has been made to assess and develop solid-state lasers for the non-lethal weapons applications at which ATL and PEP are directed. A modest investment to gain an understanding of the viability and scope of NLWs based on solid-state lasers is warranted, and the results of that effort should be used to provide the focus for NLW-related solid-state laser research.

Barriers

On the basis of initial results with systems such as the running gear entanglement system, the committee recommends that ONR explore novel and quickly deployable marine barrier systems relevant to stopping larger ships and/or protecting ports—objectives encountered uniquely by the Navy.

Platforms and Sensors

Even more generally than described for weaponizing chemical NLWs, ONR should address the unique *system* needs of NLWs in platform and sensor development. Particular areas of emphasis are recommended as follows:

1. Accelerate technology programs that explore the creative use of remotely piloted and robotic vehicles to deliver NLWs. Considerable research in robotic and remote precision delivery of lethal weapons systems is well underway in many agencies. Small UAVs, UUVs, and remote-controlled surface (water) vehicles offer attractive ways to deliver NLWs at large standoff distances with greater accuracy. They also permit remote sensing with a variety of sensor types to ensure effective employment of the NLWs. Additionally, remotely piloted vehicles can achieve and sustain higher speed and acceleration and may have a greater ability to follow a rapidly moving target (such as a speeding boat) than a humanly operated vehicle. These low-cost and flexible delivery systems (such as Roboski, and low-cost UAVs such as LEWK) have the potential to greatly expand and enhance the effectiveness of NLWs. The committee does not recommend new or unique platform programs for NLWs, but, instead, it recommends creative addendums to modify and test existing small, remotely operated or robotic platforms as carriers for NLWs and their sensor systems.

2. Expand efforts to develop, improve, and better utilize existing sensor technologies for non-lethal weapons applications. Because NLWs generally have a more limited effective range than their lethal counterparts, the successful use of NLWs depends more critically on the ability to selectively and accurately hit a target. Sensors will play a critical role in determining the success of missions using NLWs. Remote sensors are especially important for these missions for gathering intelligence, identifying intruders both on land and in the water, identifying potential targets and their intent, precision targeting, and determining battle damage. In addition, remote sensors can measure, in real time, the intensity of the non-lethal munition's effect at the target and can send this information back to adjust, for example, power levels or chemical agent concentrations to obtain the desired level of effect. Much work has been done on relevant sensor technology, much of it sponsored by DOD. Low-cost, expendable sensors that measure and report RF levels, chemical concentrations, explosives, or sounds, and that could be dispensed from small, low-flying UAVs would be especially useful for many types of non-lethal weapons missions. Remote sensors suitable for robotic marine vehicles and underwater sensors to detect and target swimmers are important for missions of in-port ship protection. The committee does not recommend the independent development of new sensors, but recommends instead the identification of promising sensor programs in DOD, accompanied by creative adaptation and testing of such sensors for the tailored needs of non-lethal weapons systems.

3. Investigate acoustic detectors and sources for use in underwater NLW systems. Underwater applications present a potentially more promising scenario, however, due to the increased coupling of acoustic energy. Past investigations have considered the use of ship sonar against underwater threats. Also being investigated are underwater acoustic sources as warning or non-lethal options against such threats. Unknowns include environmental effects on fish and marine mammals.

5.4 DEPARTMENT OF THE NAVY

Recommendation: The Secretary of the Navy, the Chief of Naval Operations, and the Commandant of the Marine Corps should establish a senior-level working group to actively oversee the integration of non-lethal weapons into naval warfighting requirements, research and development programs, acquisition plans, and operations.

NLWs are shifting from limited, specialized use status to operational priority for the Marine Corps in both conventional and OOTW scenarios, and they are emerging as important for both defensive and offensive missions in the Navy. If not given senior-level attention, by both the Navy and Marine Corps however—at least for some period of time—NLWs may never receive the assessment and commitment needed to enter the development and acquisition process to meet naval needs. As the newcomer competing for resources against more traditional areas, coupled with the last few years' reliance on the JNLWD to "just take care of it," NLWs may otherwise never be fully integrated into naval force capabilities. The broad range of non-lethal weapons naval applications further compounds the problem by having many versus a single logical proponent for maturation, so that no one really "owns" the area.

The committee believes it is imperative that senior officials within the Department of the Navy, acting on behalf of naval force (i.e., Navy and Marine Corps) requirements, become knowledgeable about and take responsibility for the development and integration of non-lethal weapons systems into naval mission readiness. This requires that those with assigned responsibility for operational implementation of weapons systems, as well as for R&D, gain an appreciation of the applicability of NLWs across the entire spectrum of naval conflict from both an offensive and a defensive perspective. This can be accomplished only through active participation in a process that engages senior naval officers' personal attention. A senior working group that meets on a scheduled basis would facilitate all aspects of support for non-lethal weapons systems. Specifically, the committee believes the working group must develop a naval non-lethal weapons master plan for naval expeditionary forces.

The committee recommends that the overall structure and membership of the working group be established jointly among the Secretary of the Navy, the Chief of Naval Operations, and the Commandant of the Marine Corps and coordinate its efforts with the IPT process of the JNLWD. Significant involvement by N70 would be expected because of its role as honest broker and integrator, but other elements should be active participants. Subgroups to addresses Navy- and Marine-specific needs may be warranted, but an integrated naval plan should remain the end goal. This working group should have liaison with warfighting CINCs for their input on requirements.

To accomplish this task the working group should do the following:

- Become knowledgeable about the advancing technologies associated with NLWs;
- Understand the operational capabilities of NLWs;
- Understand offensive and defensive vulnerabilities of non-lethal weapons systems and infrastructure critical to NLWs;
- Accelerate the creation of formal requirements documents for non-lethal weapons systems;
- Ensure that adequate funding is available to support development, testing, and fielding of NLWs;
- Ensure that non-lethal weapons technologies are integrated into full weapons systems, including sensors, delivery mechanisms, and combat assessment capabilities;
- Be knowledgeable about effects data generated by the centers of excellence and of the efforts in other Services;

- Be able to articulate publicly the technological, operational, and policy issues associated with NLWs;
- Incorporate NLWs into high-level wargames, simulations, and studies;
- Create a mechanism to ensure that NLWs will become fully integrated into, and can compete fairly in, the requirements and development processes for all naval systems; and
- Publish the master plan to include lead organizational roles and responsibilities and insertion of NLWs into the future naval capabilities process.

Appendixes

A

Non-Lethal Weapons in the Architecture for Force Protection

A large number of commercially available personal watercraft occupy the waters near ports where the Navy's ships are at anchor in the harbor. Intrusions into spacing "unacceptably close" to a ship may take place innocently (for example, by civilian crafts, such as fishing boats or pleasure boats) or by forces intent on harm. Civilian opposition to a military operation offers a particularly effective cover for hostile intent by terrorists.

Many of the procedures that are emerging within the AT/FP initiative involve non-lethal weapons and procedures. When a U.S. Navy ship enters the port of a foreign country, a substantial—and growing—series of checks must be completed to assess the risk of terrorism or threats from hostile individuals or groups. As a result, additional coordination and attention are needed from the host nation before the arrival of a U.S. vessel. Because of the complex nature of a professional "sweep" to ensure security, the formation of a maritime ships security augmentation force (MASSAF) is under consideration. This force would arrive at an intended port before a ship's arrival, and it would sweep buildings close to port, ensure that the necessary security operations had been taken, and enhance security through acceptable means.

As described in Section 1.2, the primary force protection architecture for ships in ports involves layers, or zones, related to the nature of a potential threat. Any approaching watercraft could pose a potential threat if it came within a specified distance of a ship, that is, within Zone 1 (or the "outer defense bubble," in three dimensions). If that happens, action is taken to warn the approaching craft to keep its distance and also to determine if the vessel is either hostile or unaware that it is a potential threat to the ship. Warning signs, lights, audible warnings (sirens, horns), or other perimeter indicators are appropriate at this distance. If the vessel approaches closer, within Zone 2 (the middle zone), a series of non-lethal warnings or actions may be employed. These should be intense enough that any innocently intruding vessel clearly recognizes its vulnerability to attack if it continues to come closer. If the approaching craft enters Zone 3 (the inner zone), the intent of the approaching craft can be assumed to be hostile, and lethal actions may be employed.

A high level of uncertainty exists when a vessel is in Zone 2. The rules of engagement specify that every commander has the right to defend his or her own ship, and may use lethal means when necessary. Because of the short time it may take a high-speed personal watercraft to approach a stationary vessel, ROEs must be delegated to individuals able to take necessary action. If, for example, an approaching vessel is traveling at a speed of 90 knots from 2,000 to 1,000 yd, a sailor charged with ship security has limited time to make a decision and act. The sailor must have a clearly defined set of actions for dealing with increasing levels of lethality: that is, (1) assess, (2) warn, (3) threaten, (4) intimidate, (5) incapacitate (personnel or materiel), (6) disable, (7) damage (materiel), and, finally (8) destroy. Non-lethal methods allow the sailor to take steps (2) through (7) before employing lethal procedures. Crews must be properly trained and have the authority to take actions in sequence to handle complicated and rapidly changing scenarios.

Actions in Zones 1 and 2 that may be taken, or that are under consideration, as a result of the AT/FP initiative, include the following:

- *Detection.* Detection of vessels that intrude into Zone 1 is obviously necessary. Sentries, electro-optical devices, radar, and sonar may be used extensively to determine the presence of objects within a designated distance. New detection devices may be appropriate to enhance the ability to detect small boats, subsurface swimmers, approaching small aircraft, and intruders in land vehicles or on foot. Available technology for detection can meet many needs; once requirements are determined, effective systems can be designed.
- *Attention-getting actions.* Signs indicating the limits of a perimeter defense may be placed at appropriate locations to warn approaching vessels. Horns, sirens, or lights may be used to get the attention of an approaching vessel. Sentries may attempt to provide warnings, and animated warning signs may be triggered. These items represent low-technology methods readily available for implementation at minimal cost. Training in their appropriate use is required.
- *Non-lethal actions with lethal weapons.* Firing a shot across the bow of an approaching vessel is clearly overt non-lethal action that has been recognized for centuries and which represents a recognized signal that if no change in course is taken, a lethal shot may be fired. Besides endangering other activities in the area, such action would be deemed extraordinary and could be offensive to the host country providing port security. Alternative actions involving non-lethal procedures are highly preferred and are being developed.

• *Riot control agents.* A variety of riot control agents such as rubber pellets or batons, water cannons, flash bangs, pepper spray/balls, and other chemical lacrimators or irritants, may be used under the restrictions of the Chemical Weapons Convention. Combinations of agents can also be considered (e.g., mixing lacrimators with water cannons). The delivery of riot control agents to small vessels with remotely piloted watercraft or unmanned aerial vehicles may be appropriate for the distances and situations anticipated in such encounters. This option requires system design and development.

• *Detection of offending materials.* If a vessel is to be boarded, either in the AT/FP scenario or using enforcing sanctions, detection to determine the presence of offending substances onboard may be necessary. Chemical sniffers capable of detecting the presence of explosives are available, and improvements in packaging are under development. Current methods are effective only at very short range (i.e., about 1 ft) and require some sort of remotely controlled platform to get the sensor close enough to detect a substance. Future advances, while offering improvements in sensitivity, may still require remotely controlled deployment means.

• *Vessel stoppers.* Vessel stoppers, such as the running gear entanglement system, are under development. Exhaust stack blockers have been evaluated but are not attractive because of the difficulty of placing the blockage in the exhaust stack of a vessel. Casting a net across the bow of a vessel (sea anchor vessel stopping system) has been suggested; the net is attached to parachute-shaped drogues that open and impart considerable resistance to the continued motion of a vessel. Delivery of this system, or of RGES, remains a challenge. Remotely piloted small craft are being tested to assess their ability to perform this delivery function. An alternative proposal is a small craft disabler, which inserts a spear into a hull at the waterline and deploys a fin that drags in the water, making steering impossible.

• *Surface patrol vessels.* Small-craft patrols operating in conjunction with a docked ship allow closer monitoring of any vessel entering Zone 1; they are being proposed as standard operating procedure for vessels in port. The delivery of warnings, vehicle stoppers, or other items for which a close approach to an offending vessel is required may represent a substantial challenge. The Coast Guard reports that high-speed personal watercraft and other high-powered vessels frequently outrun pursuing Coast Guard vessels. A relatively inexpensive jet ski to which a remote control and monitoring system may be attached is commercially available at an estimated cost of approximately $50,000. Speeds up to 90 knots in calm water are advertised. This “Roboski” has successfully deployed RGES to stop a boat. Costs of the Roboski/RGES system are about $87,000. A Roboski platform might also be used to deploy a drag chute over a vessel; warning devices such as sirens, flashing blue lights, strobe lights; flash-bang munitions; pepper spray; blunt trauma munitions; or a water cannon. It might also be used as a ramming device. These ideas are under consideration for countering the threat of a high-speed intruding or escaping vessel.

- *Unmanned air vehicles.* Various unmanned aerial vehicles have been suggested for patrolling the airspace. One recommended by Systems Research and Development Corporation (SRDC) weighs 30 lb, has a 10-ft wingspan and 30 hours' endurance, and costs $8,500 with a data link. The loitering electronic warfare killer (LEWK) is another vehicle that can be launched from various guns or launch systems to provide over-the-horizon monitoring.

The measures described here address hazards that may approach a ship on water. Additional threats may appear underwater. Sonar monitoring can detect the presence of such threats. Actions to minimize risk if such intrusions are detected include (1) acoustics; (2) counterdiver activity; or (3) subsurface munitions (which may be lethal).

B

Non-Lethal Weapons Technology Table

The Committee for an Assessment of Non-Lethal Weapons Science and Technology undertook a survey and assessment of non-lethal weapons technologies as described in Sections 2.1 and 3.2. Table B.1 provides a consolidated presentation of that effort.

TABLE B.1 Non-Lethal Weapons Technologies

Type of Technology	Comments	If in Acquisiti
ACOUSTIC TECHNOLOGIES		
Audible and ultrasonic	Tests not reproducible in air; dependent on distance, and highly dependent on impedance match to personnel; not high priority; Gayle device is one such system; R&D funding ended in 1999. Results questionable, effects are unclear.	
Acoustic impact on personnel	Many different concepts have been proposed for creating acoustic sources capable of disabling a suspect. Effectiveness still unproven despite considerable study (problem: variability of effect and coupling energy into person).	
Acoustic impact on personnel—underwater	Acoustic coupling much higher in water than in air. Unaware of significant research on sonic NLWs for underwater use. Environmental impact must be assessed.	
Infrasound devices	Some animal studies available on the effects of low-frequency sound on animals' behavior and task performance. Research apparently abandoned.	
ACOUSTIC/OPTICAL		
Flash bang	Effective in some crowd dispersal situations and for clearing facilities. Flash-bang systems effective as a distraction; not as effective against high-level threats.	
Flash bang delivery systems		
XM84 acoustic/optical stun grenade		
66-mm vehicle-launched non-lethal grenade		
Multisensory distraction device		
Flash	Nonexplosive, flash grenade; uses array of flashbulbs.	

		Missions									
If in Acquisition, Where?	Human Effects	Deny Access	Control Crowd	Incapacitate Individuals	Stop Vehicles	Secure Buildings	Clear Facilities	Stop Boats/Ships	Establish Ship's Perimeter	Stop Swimmer	Detect Threats
Currently not funded.	Probably safe if sound level is low enough not to cause a permanent threshold shift in hearing.	X	X				X			X	
Concept.	Human effects not totally known. Human tolerance to a single exposure has been studied. Effect of continuous exposure unknown.	X	X				X			X	
Committee meeting, June 13, 2001 (see preface).	Human effects unknown.	X								X	
	Human effects unknown.	?	?							?	
Being incorporated into existing delivery systems.	Probably safe if sound level is low enough not to cause a permanent threshold shift in hearing.		X	X			X			X	
			X	X			X			X	
			X	X			X			X	
			X	X			X			X	
	Human effects unknown if subject is exposed at close range.			X			X				

TABLE B.1 Continued

Type of Technology	Comments	If in Acquisiti
CHEMICALS/MATERIALS TECHNOLOGIES		
Obscurants		
Smokes	Available for procurement with sophisticated delivery methods.	
Advanced obscurants, including IR capability	Mature technology, in use with various dispensers; IR capabilities relatively new.	
"Inks"	Could have application underwater as a disorienting tool.	
Reactants		
Combustion modifiers	Effective in testing; difficulty of delivering chemicals on moving targets a drawback. Two types have been tested: knock producers and engine runaway agents.	
Antiadditives	Generally agents that counteract lubricant additives. Effective in 1 to 2 percent concentrations, and disable antiwear and antioxidant additives in the lubricant. Targets are internal combustion engines, turbines, and gear boxes.	
Fuel contaminants	Compounds that cause stored fuels to thicken or otherwise become ineffective. Difficulty of delivery of materials can be a drawback. Generally a large amount of material is needed; the committee sees little prospect for much improvement of this characteristic.	
Lubricant contaminants	Difficulty of delivery of materials a drawback.	
Depolymerization agents	Could be useful in some scenarios. Methods of delivery remain a problem. Demonstrated rubber depolymerizers were based on an oxidation mechanism. Current tires contain antioxidants not present in previous work.	

		Missions									
If in Acquisition, Where?	Human Effects	Deny Access	Control Crowd	Incapacitate Individuals	Stop Vehicles	Secure Buildings	Clear Facilities	Stop Boats/Ships	Establish Ship's Perimeter	Stop Swimmer	Detect Threats
		X	?						X	X	
COTS.	Probably safe for use against humans.	X							X		
Programs underway at Sandia and elsewhere.	Probably safe for use against humans.	X							X		
Committee meeting, June 13, 2001 (see preface).	Human effects unknown; depends on chemical used.									X	
Former program at ECBC.	Antimateriel.				X			X			
Proposed—based on previous work; program currently not active.	Antimateriel.				X			X			
Proposed.	Antimateriel.				X			X			
Proposed.	Antimateriel.				X			X			
Proposed; some testing done in the past.	Antimateriel.				X			X			

TABLE B.1 Continued

Type of Technology	Comments	If in Acquisiti
Corrosive agents	Difficulty of delivery of materials a drawback; precise placement needed.	
Corrosive materials	Proposed to be useful against electrical components and other materiel.	
Thermites, propellants	To fuse elements of metallic platform.	
Viscosity agents	Fuel thickeners demonstrated; thixotropic gels. Difficulty of delivering chemicals is a drawback; little chance of extensive use.	
Supersolvents	To dissolve "O" rings.	
Malodorants (e.g., scatole, mercaptans)	Systems under consideration—potentially useful for area clearing and area denial. Preliminary exploration for police actions.	
Calmatives	Further research required involving effects, susceptibilities, safety, delivery methods, and so on. Studies needed of onset time vs. delivery method and mechanisms to control doses and exposures.	
Calmative agent sponge projectile	To incapacitate personnel; sponge with fentanyl derivative delivers dose. Question: What is tolerance level for dose and personal susceptibility? Linking calmative with antidote extends margin of use.	
Riot control agents	Evaluation of databases done involving chemical payloads, by ECBC; most of these are RCAs. Study of the use of CS, CN, OC summarized in IJ Research in Brief, March 1997.	
Pepper spray (OC)	In use with police actions. Coast Guard needs high-accuracy, long-range dispensing systems.	
Lacrimators (e.g., CS)	In use with police actions.	
Riot control grenade L96E1	Developed by UK Ministry of Defense; contains CS.	

		Missions									
If in Acquisition, Where?	Human Effects	Deny Access	Control Crowd	Incapacitate Individuals	Stop Vehicles	Secure Buildings	Clear Facilities	Stop Boats/Ships	Establish Ship's Perimeter	Stop Swimmer	Detect Threats
	Antimateriel.				X			X			
Suggested.	Antimateriel.				?						
Suggested by Sandia, LLNL.	Antimateriel.				X			X			
ECBC.	Antimateriel.										
Suggested.	Antimateriel.										
CEP.	Human effects unknown; lingering effects a concern.	X	X	X			X				
Under study by ECBC after lull in R&D for 10 years.	Human effects known for some calmatives. Margin of error needs to be determined.	X	X	X			X				
Under study by ECBC after lull in R&D for 10 years.	Margin of error needs to be determined.	X	X	X			X				
TIP study underway for military use, new potential systems.	Hazard depends on dosage.	X	X	X			X				
Available for procurement.	Hazard depends on dosage.	X	X	X			X				
Available for procurement.	Hazard depends on dosage.	X	X	X			X				
	Hazard depends on dosage and type of casing.	X	X	X			X				

TABLE B.1 Continued

Type of Technology	Comments	If in Acquisiti
Slippery foams and agents	Demonstrations effective; require large quantity of material to be delivered.	
Slippery foam	When spread on a walkway, makes simply walking across the area difficult; degree of delay must be sufficient to be effective; large quantity of material must be used (logistics problem).	
Rigid foam	Appropriate in specific circumstances for local security measures; deemed not to be used on personnel directly due to potentially lethal effect (blocking respiration). Appropriate in specific circumstances for local security measures.	
Rigid polyurethane foam	Rapid dispersion and hardening of foam useful for base security and barrier functions.	
Sticky foams		
Sticky thermoplastic foam	Developed for access delay, area denial, and target denial; an exceptionally tenacious material (difficult to clean up).	
Underwater sticky foam	Idea of underwater sticky foam discussed; however, work on this is unknown. Could be useful against swimmers and boats (to clog intakes).	
Stabilized aqueous foam	Large expansion ratio; for use as visual and acoustic isolation, and fire suppression; irritants could be added.	
Contaminating abrasives	Materials put into engines degrade precision parts.	
Microfibers	Technology assessment of genetic research on spider fibers (for super strength); terminated December 1998.	
Microencapsulation	Appears to have possible utility in delivery of malodorants or other chemicals? Design for pressure or temperature release needed.	

		Missions									
If in Acquisition, Where?	Human Effects	Deny Access	Control Crowd	Incapacitate Individuals	Stop Vehicles	Secure Buildings	Clear Facilities	Stop Boats/Ships	Establish Ship's Perimeter	Stop Swimmer	Detect Threats
Academic research underway.	Hazard to moving vehicles, which may become involved in a fatal crash.	X	X		X						
Demonstrated.	Persistent.	X	X		X						
Academic research underway.	Principally used as a barrier. Should not be used against individuals due to lethal potential for blocking respiration.	X				X					
Foam materials and dispensers made and tested at Sandia.	Should not be used against humans.	X				X					
Foam materials and dispensers made and tested at Sandia.	Not to be used on personnel directly, due to potentially lethal effect (blocking respiration).	X									
Committee meeting, June 13, 2001 (see preface).	Human effects unknown.							?	?	?	
Foam materials and dispensers made and tested at Sandia.	Found to be safe for human use.	X	X	X							
	Antimateriel.				X			X			
	Antimateriel.										
Academic research underway.	Depends on munition used.										

TABLE B.1 Continued

Type of Technology	Comments	If in Acquisiti
Cloggers		
Vessel exhaust stack blocker	Displacement hull boats/ships stopped with exhaust cover delivered by helicopter. Operationally difficult to position over ship. ESB tested; difficult delivery a shortcoming; helicopter delivery terminated.	
Air intake blocker	Thin film/fabric deployed over a battle tank and drawn tightly over the air intake by airflow.	
ELECTRICALS		
Pulsed current	Capacitive discharge device for stopping vehicles in high-speed pursuit; test successful and more effective than HPM.	
Sticky shocker	Wireless projectile based on stun gun technology, barbs attach to clothing, High-voltage pulses incapacitate, range 10 m. Delivers high-voltage numbing current after delivery to person. Biological effects not understood well; under investigation.	
Stun guns	Law enforcement officials use frequently.	
Taser mine		
Taser area denial device	Will fire 20 sets of darts a distance of 15 ft; considered an area-denial device. Human effects study underway.	
Taser grenade	Fires a volley of taser cartridges downrange.	
Tetherless taser	Research gap: need for a tetherless device with 90-m range.	
DIRECTED-ENERGY TECHNOLOGIES		
ELECTROMAGNETIC WAVES		
Electromagnetic pulse		
Non-nuclear EMP	Intended to stop auto engines; not effective; terminated August 1998. Some continued interest in application to stopping ships.	

		Missions									
If in Acquisition, Where?	Human Effects	Deny Access	Control Crowd	Incapacitate Individuals	Stop Vehicles	Secure Buildings	Clear Facilities	Stop Boats/Ships	Establish Ship's Perimeter	Stop Swimmer	Detect Threats
CEP.	Antimateriel.							X			
Edgewood.	Antimateriel.				X						
OS&T/ARL.	Antimateriel.				X			X			
Jaycor evaluation 2001.	Human effects unknown. Potential hazard of heart failure and death, particularly in individuals with diseased hearts.	X	X	X							
COTS.	Human effects not totally known.	X	X	X							
TIP; demonstration 2000.	Human effects not totally known.	X		X							
	Human effects not totally known.	X	X	X							
	Human effects not totally known.		X	X							
	Human effects not totally known.	X	X	X							
	Hazard depends on power used.				X			X			

TABLE B.1 Continued

Type of Technology	Comments	If in Acquisiti
Capacitor technology	New high-dielectric-constant materials are able to increase storage capacity of capacitors to improve pulsed power effects.	
Radio frequency	NOTE: Detection and countering of RF has been province of EW community; the JNLWD should not undertake competing programs or concepts with EW community. Nevertheless, devices are needed that can create deception in conjunction with use of NLWs.	
RF taggant	Systems ready to be produced if customer is identified.	
New methods to fabricate millimeter-wave sources	Using advanced lithography (such as LIGA), fabricate mm-wave sources (30-75 GHz), including high peak power (67 kW over 450 pS) and modulation for communication purposes.	
Microwave		
High/medium-power microwave sources	Technology development for vacuum and solid-state microwave sources, amplifiers, and transmitters.	
High-power microwave	Studies for HPM for defense of Navy ships (ongoing).	
High-power microwave	Functions proposed: bring down aircraft, information systems, power plants, power grids, radar, engines, antenna, automobiles, marine effects, and detect/clear mines. Many anecdotal experiments reported and attempted; high power needed (close to source), and variability of susceptibility a difficulty.	
High-power microwaves—modeling	Models indicate that higher frequency ranges are effective against electrical components; much needs to be done here.	
HPM for vehicle stopping	Ground vehicle stopper (GVS) tested moderately; initial results variable, but continued study underway to continue assessment for vehicle stopping. GVS tested (considered high risk—somewhat confusing reproducibility in different vehicles).	

		Missions									
If in Acquisition, Where?	Human Effects	Deny Access	Control Crowd	Incapacitate Individuals	Stop Vehicles	Secure Buildings	Clear Facilities	Stop Boats/Ships	Establish Ship's Perimeter	Stop Swimmer	Detect Threats
Proposed, LLNL.	Hazard depends on power used.										
	Probably safe for use on humans.										X
Program underway at Sandia.											
Research only, NRL.											
Research only, NRL.											
Concept, LLNL.	Humans exposed to this radiation will be heated at different body depths.				X			X			
Suggested.											
AFRL.					X			X			

TABLE B.1 Continued

Type of Technology	Comments	If in Acquisiti
HPM for marine engines	HPMs tested to stop marine engines with some (inconsistent) success; other systems being considered pending further testing; JFC study claims some effectiveness against ships.	
Millimeter wave	VMAD under development as antipersonnel device; susceptibility to countermeasures unknown.	
HPM munitions	Explosive HPM generating round.	
E-bomb	Bomb-deployed RF generator. Two types proposed: explosive-driven and capacitor-driven (Marx generator).	
Magnetic pulse	Uses explosive generation of very high magnetic fields. Magnetic field is projected at target through antenna. Fields are calculated at about 40 tesla. Range of effect is short, about tens of meters. Most effective on electronics, and less on explosives. Will require very close range to have biological effect.	
Infrared		
Lasers		
PEP	DF/HF lasers—a pulsed DF laser prototype; consider system upgrade, program to understand bioeffects. Continued evaluation needed.	
COIL	High continuous power (100s kW). Consumes large amount of reactants per second; requires special material handling capabilities. ACTD under consideration (June 2001).	
CO_2 laser heat gun	Commercial systems in existence.	
Semiconductor lasers	Mid-IR to 25 μm, continuous operation at higher powers; quantum well, quantum cascade.	

		Missions									
If in Acquisition, Where?	Human Effects	Deny Access	Control Crowd	Incapacitate Individuals	Stop Vehicles	Secure Buildings	Clear Facilities	Stop Boats/Ships	Establish Ship's Perimeter	Stop Swimmer	Detect Threats
GVS: pre-procurement; other HPMs: under consideration; JFC study.								X	X		
Pre-Milestone A.	Human effects not totally known, especially for exposure at close range.	X	X						X		
Proposed.	Hazard depends on power used.				X			X			
JFC.	Hazard depends on power used.				X			X			
Work from DTRA. Appears to be mostly a paper study.	Human effects not totally known.				?			?			
TIP; $2 million in FY93-94; current review of program with potential startup.	Human effects not totally known, including eye injuries.	X		X							
	Not for use against humans.				X			X	X		
	Not for use against humans.	X		X							
NRL.	Not for use against humans.										

TABLE B.1 Continued

Type of Technology	Comments	If in Acquisiti
Visible		
Laser sources		
Laser illuminators	Systems available for purchase. Saber 203 used in Somalia. Test models of the "Dissuader" flashlight exist. HALT: rifle-mounted unit with flicker option.	
Laser dazzler	Dazzling effect of veiling glare laser on cockpit under study.	
Lens fluorescer project	UV irradiation of lens in eye causes fluorescence; laser selection to be made; tests on lenses from eyebank may commence; JNLWD funding of $200,000.	
Argon laser scattering obscuration	Available if effective.	
Laser designator around ship's perimeter	Idea to "paint" perimeter warning lines on water around ship with a scanning laser.	
Holographic imagery projected	Proposed as a system; no program yet.	
White light		
Strobes (omnidirectional or directed)	Some effect noted; not high priority.	
Stroboscopic devices		
Strobe light	Flickering light disorients suspect.	
High intensity	Some effect noted; not high priority.	
Ultraviolet		
Laser ionizer	Advantages not known yet.	

		Missions									
If in Acquisition, Where?	Human Effects	Deny Access	Control Crowd	Incapacitate Individuals	Stop Vehicles	Secure Buildings	Clear Facilities	Stop Boats/Ships	Establish Ship's Perimeter	Stop Swimmer	Detect Threats
USAFRL 2001 evaluation.	HALT may not be eye-safe at close range (> 6 m). Saber is eye-safe.	X	X								
TIP study underway.	Low-level radiation is eye-safe.	X							X		
	Human effects unknown.	X	X	X							
	Results unknown.										
Committee meeting, June 13, 2001 (see preface).	Eye-safe if low-level laser used.								X		
	No hazards against humans.		X								
	Human effects not totally known.		X	X							
Concept, LLNL.	Human effects not totally known.		X	X							
	Human effects not totally known.		X	X							
	Human effects not totally known.										

TABLE B.1 Continued

Type of Technology	Comments	If in Acquisiti
BARRIERS AND ENTANGLEMENTS		
Barriers		
Spikes and spike strips for tires	RoadSpike for high-speed pursuit.	
Caltrops	Used in the field (for centuries!).	
Concertina wire		
Jersey walls		
Portable vehicle-arresting barrier (PVAB)	Demonstrated in tests to effectively stop speeding cars. Concern for safety of passengers during rapid deceleration.	
Entanglements		
Deployable entanglements and barriers	Materials such as concertina wire effective; increased barrier capability when used with other materials such as foams.	
Webshot nets	Projectile-delivered antipersonnel net; range 30 m.	
Entanglement grenade	Fires net over crowd.	
Nets at sea	Sea testing of RGES underway; challenge to find effective delivery vehicle; antipersonnel net available for procurement; net mines emerging. Coast Guard needs boat- and helicopter-launched systems.	
Underwater deployable nets	Nets could be robotically deployed with attached buoys that inflate to snare and raise swimmers to surface.	

		Missions									
If in Acquisition, Where?	Human Effects	Deny Access	Control Crowd	Incapacitate Individuals	Stop Vehicles	Secure Buildings	Clear Facilities	Stop Boats/Ships	Establish Ship's Perimeter	Stop Swimmer	Detect Threats
Developed by INEEL OLETC.	May result in lethal crash.				X						
COTS.	Puncture and laceration risk.				X						
	Puncture and laceration risk.	X	X			X				X	
		X			X						
CEP.	May cause injuries when stopping high-speed vehicles.	X			X						
Materials and dispensers made and tested at Sandia.	Puncture and laceration risk.	X	X		X	X					
Foster Miller Co. product.	Probably safe for human use.		X	X							
	Hazard of the casing needs study.		X	X							
Compressed air launch from boat and helicopter demonstrated.		X						X	X		
Committee meeting, June 13, 2001 (see preface).										X	

TABLE B.1 Continued

Type of Technology	Comments	If in Acquisiti
KINETIC-ENERGY TECHNOLOGIES		
Blunt impact projectiles		
Sting balls, rubber balls, batons		
	Coast Guard testing accurate trajectory rounds (foam form and fin stabilized) for 12-gauge shotgun.	
Non-lethal crowd dispersal round	A 40-mm round with 48 sting balls. Degree of effectiveness and expected level of permanent damage being modeled; measures of effectiveness need to be determined.	
66-mm vehicle-launched non-lethal grenade	66-mm vehicle-launched round with sting balls, 50- to 100-m range; the XM99 contains 200 rubber balls, each 0.4 g. Degree of effectiveness and expected level of permanent damage being modeled; measures of effectiveness need to be determined.	
Beanbag rounds	Effective, but accuracy is relatively poor. USCG has chosen not to continue use.	
Sponge grenades	Soft, blunt nose minimizes injury while delivering sting.	
Baton projectiles	Rubber baton shapes fired in crowds for control.	
Ring air foil	Donut-shaped projectile, more accurate than other NLW rounds; range: 40 m; OC-dispensing feature under development. Program halted despite positive results.	
Fin-stabilized projectiles	Coast Guard tests underway.	
Water cannon	Navy tactic for crowds and unruly situations close to ship. Technology opportunities exist for improved capability.	

		Missions									
If in Acquisition, Where?	Human Effects	Deny Access	Control Crowd	Incapacitate Individuals	Stop Vehicles	Secure Buildings	Clear Facilities	Stop Boats/Ships	Establish Ship's Perimeter	Stop Swimmer	Detect Threats
CEP.											
	Human effects of heavier projectiles not totally known. Light projectiles present hazards to the eye.										
	Human effects not totally known.		X	X			X				
	Eye hazard needs to be studied.	X	X	X							
	Eye hazard needs to be studied and human effect of casing is unknown.	X	X	X							
	Human effects not totally known.	X	X	X							
COTS.	Human effects not totally known.	X	X	X							
COTS.	Human effects not totally known.	X	X	X							
NIJ-Guilford Engineering.	Human effects not totally known.	X	X	X							
	Human effects not totally known.	X	X	X							
Available as a tactic.	Can be hazardous at close range.	X	X	X							

TABLE B.1 Continued

Type of Technology	Comments	If in Acquisiti
Bounding non-lethal munition		
Modular crowd control munition (MCCM)	Contains 600 PVC sting balls. Degree of effectiveness and expected level of permanent damage being modeled; measures of effectiveness need to be determined.	
Vortex ring gun	Demonstrated.	
Water barrier ship self-defense	Explosive detonation below water generates plume of water designed to prevent penetration by sea-skimming missiles. Similar technique might also be used to prevent small boats from penetrating defense.	
ENABLING TECHNOLOGIES		
SENSING TECHNOLOGY		
Electromagnetic	RF, microwave, optical sensors are extensive in DOD.	
Radar	Waterside security need for easily portable, quickly set-up system.	
Wide/ultrawide band	Good for imaging through walls; available for procurement; short-pulse radar able to detect heartbeat and breathing through walls.	
Pulsed radar	New, inexpensive miniature transponders can improve short-range motion sensing, distance measurements, mine detection, explosives diagnostics, bridge inspection, and security measures; short-pulse radar able to detect heartbeat and breathing through walls.	
IR focal plane array	128×128 solid-state focal plane array imager operating at liquid nitrogen temperatures.	
FLIR	Waterside security need for easily portable, quickly set-up system.	

		Missions									
If in Acquisition, Where?	Human Effects	Deny Access	Control Crowd	Incapacitate Individuals	Stop Vehicles	Secure Buildings	Clear Facilities	Stop Boats/Ships	Establish Ship's Perimeter	Stop Swimmer	Detect Threats
	Human effects not totally known.	X	X	X							
	Human effects not totally known.	X	X	X							
	Hazard depends on munition used.	X	X	X							
NSWCDD.								X	X		
		X	X			X			X		X
	Safe for humans at low power.								X		X
Through-Wall Sensor working group, NIJ, no funding 2000.	Safe for humans at low power.					X	X				X
LLNL.	Safe for humans at low power.	X	X			X	X		X		X
NRL.	No known human effects.					X			X		X
	No known human effects.								X		X

TABLE B.1 Continued

Type of Technology	Comments	If in Acquisiti
Acoustic	Appropriate for special situations.	
Bullet tracker	Two methods to track sniper's bullet exist, one based on acoustic sensors, the other on infrared sensors. Demonstrated capability to sense and point TV camera automatically in 0.3 s.	
Chemical		
Explosives detection	Improved instruments are needed for detection from remote platforms (e.g., small UAV and handheld portable applications). Non-direct contact detection methodologies (standoff) very desirable but so far not possible.	
Ground sensors	Unattended ground sensors to accompany non-lethal weapons operations to gather intelligence.	
Smart buoys	Gather intelligence, broadcast warnings when deployed around ship's perimeter. Autonomous or semiautonomous control envisioned.	
TECHNOLOGIES TO DELIVER NLWs		
Weapon systems to deliver materials		
Mortars, grenade launchers, smoke generators	Combustible mortar: testing underway; 81-mm mortar: testing underway; reducing integrity of shell to reduce lethality; effective over 25 m^2.	
NLW launcher	Launcher for NLW with variable velocity correlated with rangefinder to adjust exit velocity to distance of target.	
Overhead liquid dispersal system (OLDS)	Device that bursts to dispense liquids or aerosols above designated area in isotropic pattern.	
Small arms munition (OICW)	Non-kinetic munition using airburst rounds for antipersonnel and antimateriel loads; 5- to 2,000-m range.	

If in Acquisition, Where?	Human Effects	Missions: Deny Access	Control Crowd	Incapacitate Individuals	Stop Vehicles	Secure Buildings	Clear Facilities	Stop Boats/Ships	Establish Ship's Perimeter	Stop Swimmer	Detect Threats
									X	X	X
	Probably safe for human use.										X
	Safe for human use.								X		X
Co-CINC sponsor.	Safe for human use.	X	X			X	X				X
Committee meeting, June 13, 2001 (see preface).	Safe for human use.								X		X
Pre-Milestone A.	Munitions of large mass can present human hazards. Lightweight projectiles present eye hazards. Grenade casings can be injurious.		X								
	Lower risk of injury than from velocity weapons. Still need to know human tolerance to munitions.		X								
TIP.	Hazard depends on munition used.		X	X					X		
Pre-Milestone A.	Hazard depends on munition used.		X	X							

TABLE B.1 Continued

Type of Technology	Comments	If in Acquisiti
Attachment to guns (rifles, pistols, shotguns, machine guns, naval guns)	Under-barrel tactical delivery system (pneumatic); Service interest not yet obvious.	
Under-weapon OC dispenser	Lightweight, 15-ft range.	
Missiles, rockets	ERGM design and analysis underway; frangible or combustible casings under study to develop non-lethal delivery; 2.75-inch rocket platform being studied for NLW applications.	
Bombs		
Smart fish	Munition dropped upstream from hydroelectric plant enters penstock to disable power plant; claim of estimate of 14-day disruption to make repairs (seems to be unreasonably short).	
Minnow	Small munition able to enter cooling pond and cooling lines to heat exchanger, then detonate.	
Torpedoes	Minimal investigation for NLWs.	
Mines	Non-lethal mines considered on many occasions on land; little consideration for them in water.	
UAVs	Testing underway for numerous scenarios (extensively studied for many tactical situations, lethal and non-lethal). Hand-launched UAVs desirable for ship's perimeter protection. LEWK, FASM are examples; loitering submunition study made. LEWK currently being tested in prototype.	
NLW dispenser drone	Dragon drone; aerial dispenser system for various NLWs; uses GPS-guided dispensing system.	
Unmanned powered parafoil	Unmanned powered parafoil as remote-controlled aerial spray dispenser for NLWs.	
Pioneer—remotely piloted vehicle	Concept: reconnaissance, surveillance, target acquisition, short out power lines, artillery adjustment, damage assessment.	

		Missions									
If in Acquisition, Where?	Human Effects	Deny Access	Control Crowd	Incapacitate Individuals	Stop Vehicles	Secure Buildings	Clear Facilities	Stop Boats/Ships	Establish Ship's Perimeter	Stop Swimmer	Detect Threats
	Hazard depends on munition used.		X	X							
2000, MCWL.	Human and environmental effects unknown.		X	X							
CEP.	Hazard depends on munition used.										
JFC.	Antimateriel										
LLNL.	Antimateriel										
	Hazard depends on munition used.										
	Hazard depends on munition used.	X		X	X				X		
	Hazard depends on munition used.		X						X		X
1996, MCWL, NSWC, Indian Head.	Hazard depends on munition used.		X					X	X		
1997, EBCC, NSWCDD.	Hazard depends on munition used.		X						X		
	Antimateriel.		X						X		X

TABLE B.1 Continued

Type of Technology	Comments	If in Acquisiti
MAVs	Hand-launched electrically powered microplanes as platforms to place tags and sensors and munitions.	
Land vehicles	Variety of wheeled and tracked vehicles from a primary platform for strategy and tactics for using NLWs.	
Robots	Applications examined for bridge defense, perimeter security, in-building communication relay; airfield denial. Research ongoing, studying decentralized control of cooperative robots to carry out tasks such as communication relay, navigation, searching, and intrusion detection.	
Robotic jet ski	Prototype demonstrated as potential sensor or weapons platform. Demonstration with RGES for stopping small boats is underway. A prototype "RC Ship Sentinel" is undergoing tests (June 2001).	
UUVs	UUVs have potential to detect, interrogate, and deliver NLWs.	
MARKERS, DYES, AND TAGGANTS		
UV-light visible	One form of a much broader set of dyes, markers, and taggants that can be useful for both identification and psychological operations. Many commercially available materials in use to mark and identify people and vehicles.	
IR-visible—reactive	For friend-or-foe identification. Additive to fuel that makes exhaust emit IR signature.	
Pain ball guns	Commercially available; potentially useful to deliver chemical agents.	
Taggers—active		
RF taggant	Using GPS and transmitter, encase taggant in a "super sticky bullet" to pinpoint fleeing vehicles. Systems ready to be produced if customer identified.	
Laser designator around ship's perimeter	Idea to "paint" perimeter warning lines on water around ship with scanning laser.	

		Missions									
If in Acquisition, Where?	Human Effects	Deny Access	Control Crowd	Incapacitate Individuals	Stop Vehicles	Secure Buildings	Clear Facilities	Stop Boats/Ships	Establish Ship's Perimeter	Stop Swimmer	Detect Threats
JFC.	Antimateriel.		X						X		X
COTS.											
JFC.		X									X
NSWC-D.								X	X	X	X
									X	X	X
	Hazard depends on intensity.										X
	May not be eye-safe.										X
COTS.	Can be eye hazard.	X	X	X							
	Hazard depends on intensity.										X
	Probably safe for use with humans.										X
Committee meeting, June 13, 2001 (see Preface).	Eye-safe if low-level laser used.								?		

C

Discussion of Health Effects of Non-Lethal Weapons

C.1 INTRODUCTION

Antipersonnel non-lethal weapons must yield statistically a very small percentage of permanent damage to people. Yet to be effective, significant amounts of energy, or biological change in the case of chemical systems, must often be imparted. Thus, the dilemma—or challenge—is to identify susceptibilities of the human to the potential energy forms and to design non-lethal weapons systems that operate within the bounds of effectiveness well short of permanent damage. Initial guidance on the avoidance of permanent damage has been gleaned from the knowledge base for automotive crash tolerance limits for kinetic-energy weapons and from occupational or public exposure limits that have been developed for lasers, other forms of light, acoustic and electrical sources, chemicals, and microwaves. Exposure limits are based on physiological parameters, but because the effectiveness of NLWs may result from either physiological or psychological responses by the targeted human, both areas of human response must be understood. Non-lethal weapons having blunt trauma effects were exploited early because there is considerable history and familiarity with blunt trauma. Other energy sources are now being exploited as well. Addressing each delivery form in turn, this appendix discusses the type(s) of effects resulting from exposure, the mechanism of damage, current or recent research and available data, and differences among different systems, and gives an assessment of the knowledge base.

C.2 KINETIC ENERGY

Effects of Kinetic-Energy Rounds

The use of kinetic-energy munitions in NLWs has a long history, beginning with the police baton and the water cannon. A large number of other weapons have been developed to inflict pain on targets for the purposes of area denial and/or crowd control. Most non-lethal kinetic munitions are blunt objects that are designed to strike the body to inflict temporary pain or discomfort. They can vary in size from a baton round with a mass of 140 gram (g) to plastic pellets with a mass of less than a gram. Their muzzle velocities also have a large range (30 to 500 m/s). For the most part, the risk of causing a fatality is very low. However, the risk of permanent injury is higher—to the head, eyes, face, lungs, heart, liver, or ribs, most commonly. (See Section 2.7 for data from the United Kingdom on the use of kinetic rounds in Northern Ireland.)

The spectrum of injuries sustained by those struck by kinetic-energy munitions relates not only to variations in the types and velocities of these rounds but also to the large variation in human tolerance to blunt impact. Osteoporotic females are more at risk to sustain bone fractures than are young healthy males. It is suspected that ventricular fibrillation of the heart caused by blunt impact may also be related to a pre-existing heart condition. So it is not possible to cite a single number, such as projectile speed, to define human tolerance. Instead, human tolerance needs to be defined in terms of a probability of injury for the population for a given input parameter, such as the force of impact.

The current approach is to employ a statistical technique known as Logist analysis, which uses available experimental data to determine the likelihood of injury to the general population. A sample set of Logist curves is shown in Figure C.1, in which the probability of injury as a function of force is depicted. The degree of injury can be selected to produce curves that are non-injurious (effective weapon) to those that cause permanent injuries or death. However, for non-lethal kinetic-energy rounds, there are very few data that can be used to produce such curves, because most of the data on blunt impact have been generated for the automotive crash environment. The difference between these two types of blunt impact is important to recognize—in automotive crashes, the speeds are lower than those of kinetic-energy munitions, while the mass or weight of the body segments involved is much higher.

Work has been done on interpreting chest injuries at least semiquantitatively. One approach couples the viscous criterion[1] with a simple mathematical model

[1] Viano, David C., and Veng-Kin Lau. 1983. "Role of Impact Velocity and Chest Compression in Thoracic Injury," *Aviation, Space and Environmental Medicine,* Vol. 54, pp. 16-21.

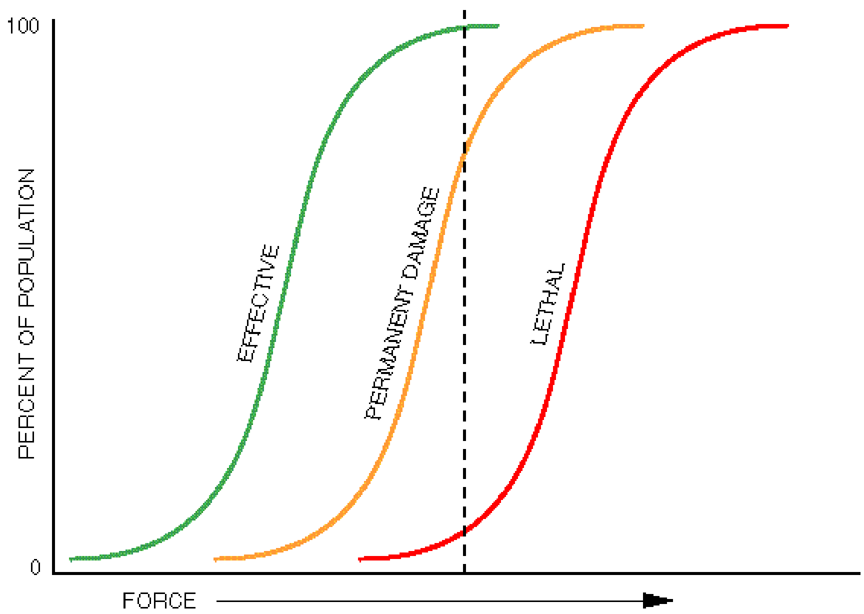

FIGURE C.1 Hypothetical Logist plot of probability of injury versus force of impact. SOURCE: Kenny, John M., Human Effect Curves (viewgraph) in "The Human Effects of Non-Lethal Weapons," briefing to the committee on April 30, 2000, Applied Research Laboratory, Pennsylvania State University, State College, Pa.

of the chest, developed by T.F. Lobdell[2] for the prediction of automotive chest injuries from frontal impact. The viscous criterion (VC) states that for the chest, the instantaneous product of chest velocity (V), expressed in meters per second, and chest compression (C), expressed as a fraction of the original chest depth, should be 1.0 m/s or less for non-life-threatening injuries. When the velocity of impact is plotted against the effective mass of the chest involved in the impact on a log-log plot, the line for VC = 1.0 is a straight line, as shown in Figure C.2. For automotive impacts, the velocities involved are generally below 10 m/s and the masses involved are usually above 1 kilogram (kg). In contrast, kinetic-energy rounds and the casings that are used to deliver these rounds have velocities in the range of 15 to 100 m/s but only tens of grams to approximately 100 grams of mass. If data for these rounds are plotted on the same curve, it is

[2]Lobdell, T.F. 1972. "Impact Response of the Human Thorax," *Proceedings of the Human Impact Response Measurement and Simulation Symposium,* General Motors Research Laboratories, October 2-3, 1972, Plenum Press, New York-London.

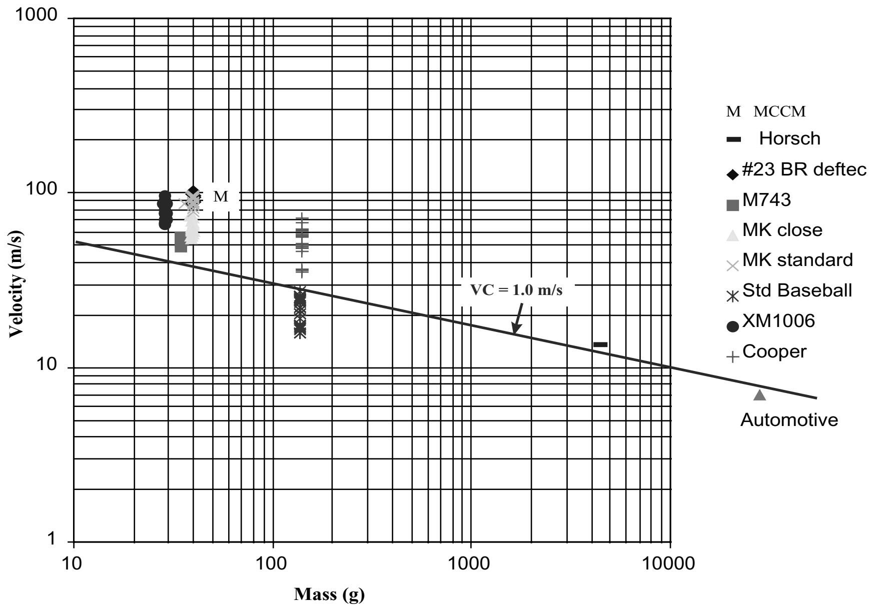

FIGURE C.2. Hypothetical study of chest injuries based on the viscous criterion. SOURCE: Lobdell, T.E., C.K. Kroell, D.C. Schneider, W.E. Hering, and A.M. Nahum. 1972. "Impact Response of the Human Thorax," *Proceedings of the Human Impact Response Measurement and Simulation Symposium,* General Motors Research Laboratories, October 2-3, Plenum Press, New York-London.

seen that there is a possible risk of chest injury from many of the rounds, based on the predictions of the Lobdell model and the VC. An estimate of the tolerance of the heart to ventricular fibrillation was provided by C.K. Kroell et al.[3] It was found that for impacts to the sternum in the range of 12.9 to 30.7 m/s, the critical value for VC for a 50 percent probability of ventricular fibrillation is 1.46 ± 0.31 m/s. The values of VC would go up if the fibrillation was accompanied by heart rupture.

Mechanisms of Injury Derived from Crash Impact Research

To understand how a body region is injured by a blunt impact, we resort to the accumulated knowledge in the field of impact biomechanics, a branch of

[3]Kroell, Charles K., Stanley D. Allen, Charles Y. Warner, and Thomas R. Perl. 1986. "Interrelationship of Velocity and Chest Compression in Blunt Thoracic Impact to Swine II," *30th Proceedings of the Stapp Conference,* SAE Paper No. 861881, Society of Automotive Engineers, Warrendale, Pa.

science that applies the basic principles of mechanics to biological systems, such as the human body. One of the branches of impact biomechanics is the study of injury mechanisms, that is, how the injury is caused. It is beyond the scope of this appendix to go into a detailed discussion of injury mechanisms from head to foot. The reader is referred to the work of Albert I. King[4] for what is known about automotive-related impact injury mechanisms.

Several examples illustrate biomechanical aspects of blunt impact injury. Ribs can fracture when a non-lethal round impacts the chest or when the torso impacts a steering wheel. In both cases, the rib is bent and the inside surface of the rib goes into tension. Since bone is weak in tension, fracture of the rib will begin on the inside surface when the deflection of the rib reaches about 70 mm.

Similarly, in high-speed blunt impacts to the chest (more than 30 m/s), the heart can go into ventricular fibrillation (ineffective pumping of blood) if the impact occurs at or just prior to the T-wave of the electrocardiogram cycle; that is, after the main signal has been sent to the ventricle to contract and to expel blood into the aorta, the heart muscle goes into a refractory state for a short time, the period of the T-wave. If the heart receives an impact at that time, the signal to the ventricle is blocked for the next cycle and the ventricle goes into fibrillation. In a study of 24 cases of baseball-related impacts to the chest, mostly against young children, none of the victims who went into ventricular fibrillation could be revived, even if immediate cardiopulmonary resuscitation (CPR) was administered. The probability of this happening with a non-lethal munition is very low, but not zero. The exact mechanism as to why the conduction of the signal for the ventricle to contract is interrupted is still being debated. If due to a direct impact to the heart by the chest wall, then the condition can be prevented by the use of a chest protector. However, if the mechanism of injury is the passage of a pressure wave through the organ, the injury can be prevented only by attenuating the wave before it reaches the heart.

Laceration of the lung can be due to contact of the lung with the broken end of a rib, while contusion of the lung is more likely due to the same pressure wave effect described above. However, the relationship between pressure magnitudes and severity of lung injury is not fully known or understood.

Other examples of injury mechanisms consider brain injury, abdominal injury, and spinal injury. For the brain, a blunt impact to the head causes local deformation of the skull and movement of the head. This movement can be in the form of a translational, or linear, acceleration and/or a rotational, or angular, acceleration of the head. Current knowledge regarding mild traumatic brain

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[4]King, Albert I. 2000. "Fundamentals of Impact Biomechanics: Part I—Biomechanics of Head, Neck, and Thorax," *Annual Review of Biomedical Engineering*, Vol. 2, Eds. Martin L. Yarmush, Kenneth R. Diller, and Mehmet Toner, Annual Reviews, Palo Alto, Calif., pp. 55-81; King, Albert I. 2001. "Fundamentals of Impact Biomechanics: Part II—Biomechanics of the Abdomen, Pelvis, and Extremities," *Annual Review of Biomedical Engineering*, Vol. 3, Ed. Roselyn Lowe-Webb, Annual Reviews, Palo Alto, Calif., pp. 27-55.

injury (MTBI) indicates that the cause is a combination of both forms of acceleration, which can generate shear and pressure in the brain tissue. The precise mechanism as to how these factors produce MTBI, including concussion and mental confusion, is still being studied.

Injuries to the solid organs of the abdomen, such as the liver, occur as the result of compression of the organ by the abdominal wall or rib cage. The velocity of the abdominal wall is also a factor in causing the organ to rupture. In contrast, the risk of spinal injury is very low; in fact, it is virtually impossible to rupture an intervertebral disc in the neck or lumbar spine with any kind of a single impact to the body unless there is a massive fracture of vertebral bodies immediately adjacent to the disk.[5]

Because of the eye's fragile structure and high deformability, any increase in ocular pressure due to impact by a blunt projectile can cause permanent injury to several different parts of the eye. In particular, the vitreous humor (a gel-like material) in the rear of the eye, which is in contact with the retina, can produce retinal laceration and detachment if deformed. Retinal injuries are frequently permanent and non-restorable.

From these limited examples, it can be seen that even after 60+ years of automotive safety research in impact biomechanics, the mechanisms of injury of many body regions are not fully known or well understood. Non-lethal kinetic-energy weapons add a new dimension to the problem because the speeds involved are much higher and the masses involved are much lower.

Recent and Current Human Effects Research on Kinetic-Energy Munitions Experimental Studies

Research on the human effects of kinetic-energy rounds has been conducted over the past two decades by many investigators in the United States, the United Kingdom, and elsewhere (see below, Cooper and Maynard, 1986).[6] Among the kinetic-energy munitions that have been studied, rubber-coated steel balls and sponge grenades have been assessed in animal studies. Penetration of the thorax and abdomen of the pig was investigated using these munitions. Animal studies on the fracture risk of the mandible and ribs as well as on the potential of injury to the heart, lungs, and intestines have also been conducted. Cadaveric studies on the effects of baton rounds on the chest and of kinetic-energy rounds on brain contusion and skull fracture have either been completed or are ongoing. A

[5]King, Albert I. 1993. "Injury to the Thoraco-Lumbar Spine and Pelvis," *Accidental Injury: Biomechanics and Prevention,* Eds. Alan Nahum and John W. Melvin, Springer-Verlag, New York. pp. 441-443.

[6]Cooper, G.J., and R.L. Maynard. 1986. "An Experimental Investigation of the Biokinetic Principles Governing Non-Penetrating Impact to the Chest and the Influence of the Rate of Body Wall Distortion Upon the Severity of Lung Injury," *Proceedings of the IRCOBI European Impact Biomechanics Conference*, Zurich, Switzerland.

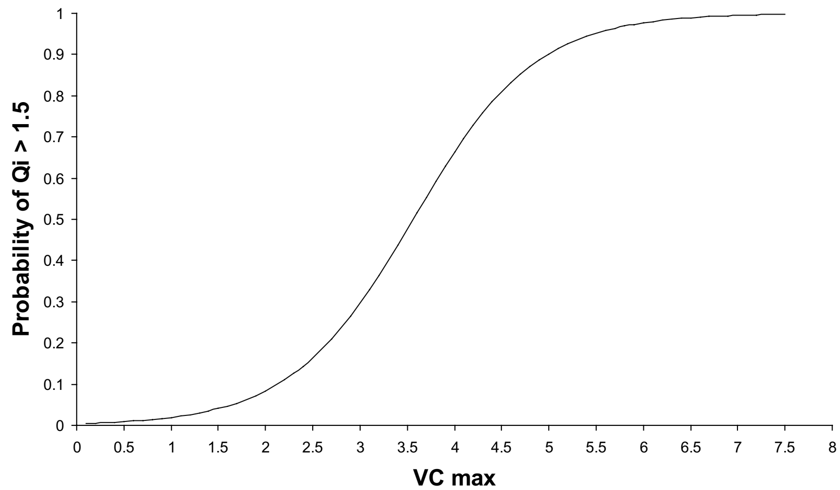

FIGURE C.3 Logist analysis of lung contusion as a function of VC. SOURCE: Cooper, G.J., and R.L. Maynard. 1986. "An Experimental Investigation of the Biokinetic Principles Governing Non-Penetrating Impact to the Chest and the Influence of the Rate of Body Wall Distortion upon the Severity of Lung Injury," *Proceedings of the IRCOBI European Impact Biomechanics Conference,* Zurich, Switzerland.

human-surrogate rib cage, called the three-rib device, has been developed for testing other types of blunt munitions of equivalent kinetic-energy levels. At the present time, a study using the three-rib device to assess the response of the rib cage to a variety of munitions, including the sponge grenade, the beanbag, and other munitions, is in progress. The impact of sting balls (light plastic balls) on porcine eyes is also being studied. It is not clear if accurate biomechanical measurements are being made along with the study of injury potential.

The early work of Cooper and Maynard studied the effect of blunt projectiles on the lung. A large series of porcupine experiments (43 tests) was conducted to evaluate lung contusion, which was defined in terms of an increase in lung weight. A 50 percent increase in weight was considered unacceptable. A Logist plot in terms of VC is shown in Figure C.3.

Ventricular fibrillation tests were conducted on swine by Kroell et al.[7] In the 41 tests conducted at impact speeds ranging from 9.7 to 30.7 m/s, with impactors ranging in mass from 4.9 to 21 kg, there were 11 cases of ventricular fibrillation

[7]Kroell, Charles K., Stanley D. Allen, Charles Y. Warner, and Thomas R. Perl. 1986. "Interrelationship of Velocity and Chest Compression in Blunt Thoracic Impact to Swine II," *30th Proceedings of the Stapp Conference*, SAE Paper No. 861881, Society of Automotive Engineers, Warrendale, Pa.

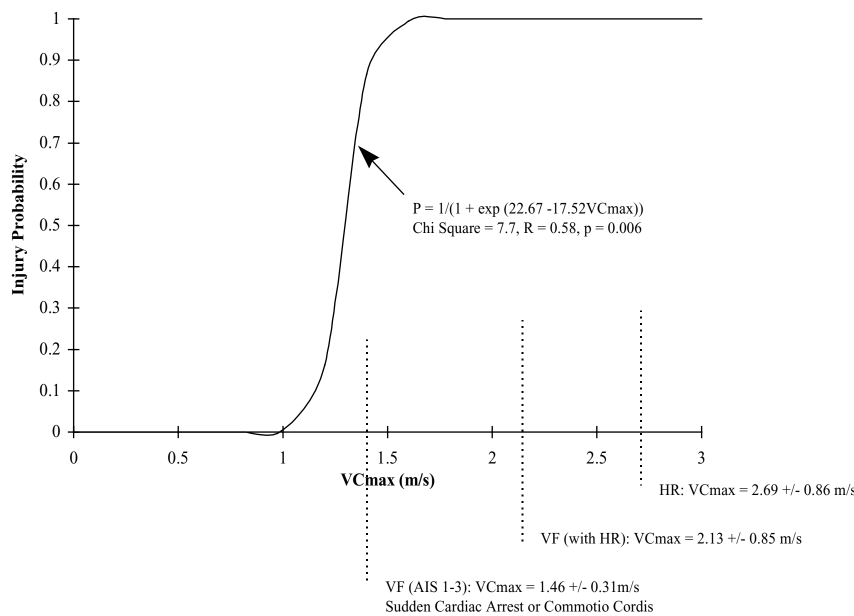

FIGURE C.4 Logist analysis of ventricular fibrillation (VF) as a function of VC. SOURCE: Kroell, Charles K., Stanley D. Allen, Charles Y. Warner, and Thomas R. Perl. 1986. "Interrelationship of Velocity and Chest Compression in Blunt Thoracic Impact to Swine II," *30th Proceedings of the Stapp Conference,* SAE Paper No. 861881, Society of Automotive Engineers, Warrendale, Pa.

and 21 cases of heart rupture. In the non-lethal weapons context, ventricular fibrillation is more relevant. A Logist curve for ventricular fibrillation as a function of VC is shown in Figure C.4. As mentioned above, the value of VC for a 50 percent probability of ventricular fibrillation is 1.46 ± 0.31 m/s. (Note also the steepness of the transition from no harm to irreversible effect. This is attractive for non-lethal weapons design in allowing a fairly crisp threshold for establishing margins of safety.)

Cadaveric tests on the tolerance of the chest to blunt projectile impact (batons) weighing 30 and 140 g and traveling at speeds of 20, 40, and 60 m/s were carried out by Bir.[8] A total of 13 cadavers was used and a total of 21 tests was conducted, with a maximum of 3 tests on any given cadaver. If a rib fracture was

[8] Bir, Cynthia A. 2000. "The Evaluation of Blunt Ballistic Impacts of the Thorax," Ph.D. dissertation, Wayne State University, Detroit, Mich.

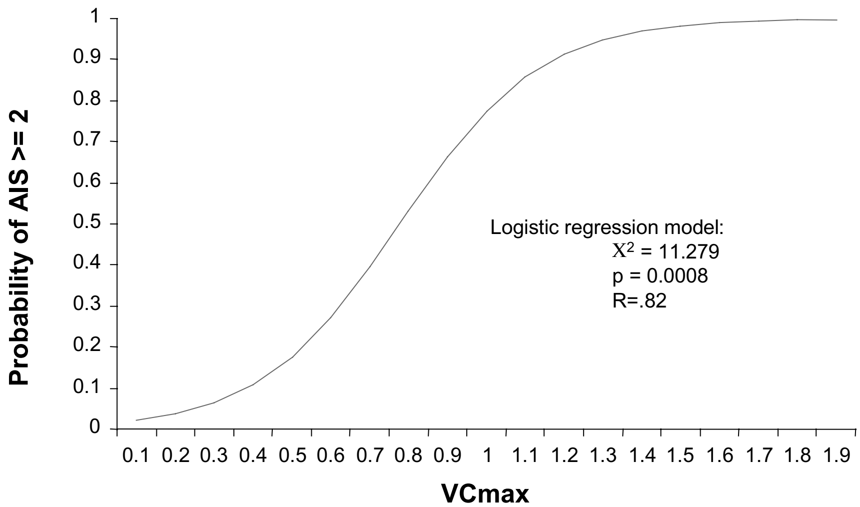

FIGURE C.5 Logist analysis of rib fracture tolerance as a function of VC. SOURCE: Bir, Cynthia A. 2000. "The Evaluation of Blunt Ballistic Impacts of the Thorax," Ph.D. dissertation, Wayne State University, Detroit, Mich.

detected either by x-ray or by palpation, testing on that cadaver was discontinued. A Logist curve for rib fracture (less than 3) as a function of VC is shown in Figure C.5. The tolerance in terms of a 50 percent probability of no more than two rib fractures is 0.8 m/s.

Although there are claims of data on brain contusion, skull fracture, maxilla fracture, and liver laceration, no tolerance curves were presented to the committee, and none were found in the open literature. The impact of sting balls on pig eyes is also being studied. Research on intestinal injury due to a pressure wave has been conducted by Yu et al.[9]

Mathematical and Mechanical Models

The only mathematical model used extensively by the military for the prediction of human effects due to kinetic-energy rounds is the Interim Total Body Model developed by Jaycor for the Army. It is an outdated spring-mass-damper

[9]Yu, James H., Edward J. Vasel, and James H. Stuhmiller. 1990. "Modeling of the Non-Auditory Response to Blast Overpressure—Gastrointestinal Tract Blast Injury Laboratory Test Techniques," Annual/Final Report to U.S. Army Medical Research and Development Command, Fort Detrick, Frederick, Md., Contract No. DAMD17-85-C-5238, by Jaycor, San Diego, Calif. (Accession No. 90 07 2037).

model that was popular some 25 to 30 years ago.[10] How the model was developed or how the data were obtained to populate the model parameters was not described to the committee. It also appears that no attempt to validate the model against experimental data has been made. Nevertheless, it is claimed that the model is capable of predicting injuries to the brain, eyes, face, lungs, heart, liver, spleen, hollow abdominal organs, and pelvic organs.

Differences in Munitions

The many types of kinetic-energy weapons described above call for a concerted research effort to try to understand the human effects of these rounds on various body regions. It can be seen from the previous sections that only a few body regions have been studied in detail and that even fewer regions have tolerance curves, and then only for a limited number of projectiles. The potential combinations of the many critical body regions with at least half a dozen different types of kinetic-energy munitions call for the development of a unifying method of tackling this problem, such as the formulation of a comprehensive finite element model of the human body, capable of simulating impacts by these munitions. During the development of such a model, the needed material parameters would be identified, and running portions of the model to simulate regional impact would identify the types of experiments needed to generate the necessary data for the material constants and for validation of the model. The proposed approach would not only reduce the number of animal and cadaveric tests needed to achieve this goal, but also make such tests more useful. At the same time, the experimental data can be used to obtain Logist curves to define human tolerance to impacts by these munitions.

Of major concern are head and brain injuries. Grenade and mortar casing fragment velocities have been measured at approximately 100 m/s; this poses a risk to both the brain and the chest.[11] It should be pointed out that there is no need to create a new finite element model of the head and brain. One already exists, and it can be adapted to kinetic-energy projectiles.[12] Tolerance of the eye to impact by munitions of different shapes and sizes, traveling at different velocities, has not been established. Perhaps a VC-type criterion could be developed to minimize the risk of permanent eye injury. Again, modeling to simulate the

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[10]Mayorga, Col Maria, USA, "Interim Total Body Model," briefing to the committee, June 12, 2001, Walter Reed Army Institute of Research, Department of the Army, Silver Spring, Md.

[11]Bir, Cynthia A. 2001. "Thoracic Injury Assessment of the Modular Crowd Control Munition (MCCM)," Final Report, Wayne State University, Bioengineering Center, Detroit, Mich., Contract No. DAAE30-99-M-0222, National Institute of Justice.

[12]Zhang, L. 2001. "Computational Biomechanics of a Traumatic Brain Injury: An Investigation of Head Impact Response and American Football Head Injury," Ph.D. dissertation, Wayne State University, Detroit, Mich.

various types of munitions should be attempted. Other areas of concern are the face (disfigurement), the ear, the thorax, the abdomen, and the genital organs.

One of the difficulties encountered in assessing the injury potential of kinetic-energy rounds is the variability of conditions under which they may be used. For example, a certain round has a design range of 50 m; that is, it can cause enough temporary pain to effectively dissuade a perpetrator from advancing toward a defending force at this range. However, if the weapon is fired at a target only 25 m away or hits an unintended target that is only 25 m away, the impact may cause not only severe pain but also possibly permanent injury. A weapon system equipped with a rangefinder and an adjustable firing pressure will help solve the problem if the tolerance of the body region is known.

In a different example, a long-range kinetic-energy mortar can be made to explode over a crowd assembling several hundred meters away. The munition used could be lightweight, high-velocity pellets that are unlikely to cause permanent injury. The canister carrying the munition can cause head injuries, however, unless it is made into harmless shards itself or lands by means of a parachute as the munition is released.

Another concern is injury to the eye. When pellets are dispersed indiscriminately over a crowd, there is again a non-zero probability that one of the pellets will hit someone's eye. The chances are very small, because the eyes constitute 0.1 percent of the frontal body surface, but policy or field command must decide if a 0.1 percent probability of a permanent eye injury is worth the risk.

Deficiencies in the Current Program

It appears that the development of kinetic NLWs is well ahead of the research on human effects. Only a few of these munitions have been tested on live animals and human cadavers, and there is no overall understanding regarding human tolerance as a function of the mass and velocity of a round. In fact, the scaling of tolerance data from the animal to the human has not been very successful in low-velocity blunt impacts simulating automotive collisions; cadaveric data were found to be much more reliable in defining human tolerance. Pathophysiological responses cannot be obtained from cadavers, yet reliable numbers on tolerance cannot be deduced from animal data. Research has been concentrated on the torso (chest and abdomen), where most of the rounds are expected to strike, but these munitions can also cause permanent and critical injuries when they strike the head, face, or eyes. A coordinated effort to study the injury potential of non-lethal kinetic-energy munitions using both animals and cadavers is needed to ensure that one truly has NLWs that fit the requirements of DOD Directive 3000.1. The present structure does not allow for any control over the development of these weapons inasmuch as human effects are not a primary consideration when a weapon is designed and developed.

Another method of assessing the mechanical effects of a kinetic munition on the human body is to use computer models to simulate the impact. The interim total body model currently in use by Army personnel, who are the leading Service expertise in this area, is outdated. In the face of a large multitude of munitions of varying mass and velocity, it is necessary for the non-lethal weapons community to develop a more sophisticated computer model that could simulate a wide range of blunt impacts. One promising approach is to take an existing finite element model of the human body used in automotive safety research and adapt it to simulate the impact of kinetic-energy munitions. Examples of these models can be found in the impact biomechanics literature (*Stapp Car Crash Journal* and the *Proceedings of the Stapp Car Crash Conference*). Finite element models can simulate a variety of impacts by different munitions at varying velocities. However, all models need to be validated against experimental data. New data using cadaveric subjects should be acquired. Alternately, animal data can be used, but finite element models of the animals would have to be developed for validation purposes. Moreover, the models need to be validated over a range of munitions fired at varying speeds.

It is concluded that although kinetic-energy munitions are not as sophisticated and versatile as some of the newer types of NLWs under development, they still have several advantages. The principal advantages are the relatively low cost of the munitions and the adaptability to existing guns and mortars. A need for weapons that can be deployed rapidly at close range to defuse a suddenly developing situation is also still important. After the tolerance of the human to impacts of kinetic-energy munitions has been determined, improvements to the weapon systems can be made. These include new projectiles and rangefinders on weapons that can control the speed of the projectile so that the target is impacted at a relatively safe speed even if it is right at the muzzle.

C.3 CHEMICAL NON-LETHAL WEAPONS HEALTH EFFECTS

Chemical antipersonnel NLWs are intended to dissuade, temporarily inhibit, incapacitate, or otherwise impede individuals and crowds from taking certain actions while causing them no lasting serious side effects. Pepper spray (OC) and tear gas (CS) are common chemical riot control agents; malodorants and calmatives are also potentially useful within the non-lethal weapons arsenal. These two riot control agents and malodorants act by being so unpleasant, either by irritation/inflammation or stench, that people leave an area.

The mechanism of actions for the riot control agents are fairly well studied. Calmatives operate by depressing the central nervous system, but while they offer some opportunity for crowd control, additional research will be required to develop substances that provide reliable human response so as to achieve cooperative behavior changes versus physiological depression. Increasing concentrations of calmatives in the body can lead to a loss of consciousness and, ultimately, death. Ideally, the level of exposure between an "effective dose" and death would be a factor as high as 10^3 to 10^4. Major R&D issues involving the use of calmatives will be (1) characterizing and quantifying the safety of the chemicals, and (2) obtaining the method of delivery that will provide the proper dose.

C.4 DIRECTED ENERGY

This section addresses directed-energy NLWs based on radio-frequency electromagnetic fields or photons either as laser light or as non-coherent light.

Radio Frequency

Radio-frequency energy, spanning direct current to gigahertz, interacts with biological tissues primarily in conversion of the energy to heat. This thermal bioresponse produces the desired effect in the current and near-term RF non-lethal weapons systems. For example, in VMADS, the first NLW that uses millimeter waves, energy is deposited within a fraction of a millimeter into the skin. This top layer is heated within a few seconds, stimulating the pain receptors but not inducing permanent damage. At present, the JWNLD program is evaluating human responses to VMADS as a function of distance. Technical reports have been published on skin heating and corneal damage in a laboratory setting. Because the millimeter wavelength that VMADS uses is not associated with an existing radar system, little prior information was developed on the safety aspects of the particular weapon concept. The fraction of energy absorbed from the beam depends on the frequency of the energy, the size and shape of the target, and the dielectric characteristics of the target, which varies significantly from tissue to tissue. For humans, these relationships and time-averaged power absorption form the basis for establishing the limits of exposure to continuous RF to avoid burning.

Recent developments in broadening the bandwidth of RF generators and the development of systems capable of producing very short pulses and very high peak power provide a glimpse into the vast, unexplored region of biological effects or human susceptibilities and potential avenues for NLWs. With such new technologies, the body would be exposed to both low- and high-frequency energy as well as to very high peak powers at some frequencies. The conventional measure, the time-averaged absorbed power, would not be a good predictor of relative safety with these systems, and it is not clear just which independent parameters should be associated with safety regulations.

Pulsed RF fields are observed to produce a variety of effects that are not understood. Moreover, leap-ahead technologies will require a much more thorough knowledge of RF interactions with the human body than currently exists. Such progress will require a prolonged effort by a multidisciplinary team of researchers skilled in a wide range of disciplines.

Lasers

Lasers are used in the non-lethal sense to function as both physiological and psychological weapons. In the former, the goal is to obscure vision, either directly by interfering with eyesight or indirectly by light scatter. In the latter, the laser is used as an illuminator to let adversaries know that they are targeted. (The latter function was used successfully in tactical situations in Somalia.) Laser weapons may be continuous or pulsed.

The method for obscuring vision can be by dazzling or by producing a form of flash blindness by photoreceptor cell saturation. This results in "afterimaging," which gradually fades with time. Only wavelengths in the visible spectrum (400 to 780 nm) produce glare and flash blindness. The eye can also be obscured by using a high-frequency laser that excites the lens to cause fluorescence within the lens. Safety issues have been and continue to be a strong focus of research because of the increasing utility of lasers in commerce, professional use, and within military circles. The potential for a specific laser to produce ocular damage depends on the type of laser, the distance from the laser to the target, the energy of the laser, and total exposure time.

Laser wavelength is one of the most important characteristics for understanding effects. Wavelengths from 400 to 1,400 nm, known as the retinal hazard region, are transmitted through the cornea and are focused on the retina. The visible spectrum includes wavelengths from 400 to 780 nm and the near-infrared includes wavelengths from 780 to 1,400 nm. The cornea and lens are capable of concentrating laser energy 100,000 times before it reaches the retina. Lasers operating in the visible or near-infrared spectra are therefore capable of producing severe photochemical and thermal choroidal or retinal damage. Lasers operating in the ultraviolet spectrum (200 to 400 nm) are also capable of producing eye damage, but the retina is usually spared because of the high absorption of ultraviolet in the outer part of the eye. Other lasers operate in the far-infrared with wavelengths above 1,400 nm and are also absorbed by the cornea and lens. These lasers may produce corneal burns or cataracts, but no energy is transmitted to the retina. Sufficient data are available for the American National Standard for safe use of lasers to be promulgated for continuous and pulsed (down to the nanosecond time frame) systems that operate at wavelengths between 180 nm and 1 mm.

To exploit lasers for use as NLWs to their maximum potential, specific programs will be required to evaluate the susceptibilities of humans to a wide range of modalities at eye-safe light intensities. This type of work follows development of guidelines on eye safety for well-studied systems but may require additional study for unexplored modalities. While the phase space requiring exploration for lasers may not be as great as that for RF systems, there is still a significant region of unknowns. It will be necessary to understand the potential for visual disruption as a function of the photon wavelength, use of multiple wavelengths, pulse shapes, interexposure intervals, and the effects of cofactors.

The use of cofactors might be considered in the search for synergistic effects of directed-energy systems. Confusion, the influence on temporary memory, and additional stages of neural disruption might be assisted by the application of multiple stimuli, properly timed. The demonstrated psychological effects related to illuminating human targets in Somalia illustrate the desirability of an accompanying psychological line of study.

C.5 ACOUSTIC NON-LETHAL WEAPONS

Non-lethal acoustic weapons have been discussed at great length in the literature as having the potential for being able to change behavior. The gross effects often described as effectors are pain, presence of irritating/aggravating noise, or the production of uncomfortable internal organ conditions. Several acoustic technologies fit under the label of non-lethal, but might be more appropriately considered in the realm of psychological tools or communication technologies, depending on the use to which they are put. Although repeated attempts have been made to develop high-intensity sound generators capable of eliciting desired results, a consistent set of reliable data, demonstrating aversive effects while not producing deafness, has not been forthcoming.

A technology of this type, useful for the same kind of applications, is that derived by sending two separate ultrasonic signals that are above the human hearing range of about 20 kilohertz (kHz). These two signals can be aimed at an individual or reflecting surface to constructively mix and produce normal audible signals, such as voice and music. Two commercial companies offer systems that could be evaluated for operational effectiveness.

Combined use of these two acoustic signal technologies offers the potential for synergy, principally in the psychological arena.

C.6 ELECTRICAL NON-LETHAL WEAPONS

The class of weapons known as tasers (aka stun guns) are NLWs acting by injection of electrical current into the human. Tasers operate either by direct contact from the weapon or by means of darts with wires attaching to the weapon. Once the dart contacts the human, high-voltage but low-amperage electrical current is discharged. The actual mechanism of action is not well studied, but the commercial devices are effective.

Proposals to develop wireless tasers are intriguing because of the potential for significant standoff.[13] Mechanisms of action must be understood and safety

[13] A reviewer of this report suggested a taser that includes a substantial round with a soft front end and a couple of darts to shoot into the clothing and convey an elecrical shock. The round could contain a capacitor charged before the round is fired.

tolerances must be developed because such a weapon, if developed, could be applied at distances that would make it difficult to identify some potential recipients. Such tolerances must be known in order to develop rules of engagement for this type of weapon, since there may be a range of tolerances depending on the age, size, gender, and other physical conditions.

C.7 BARRIERS AND ENTANGLEMENTS

Effect of Barriers and Entanglements

Most barriers and entanglement systems are designed for area denial to personnel and/or vehicles, including ships and boats. Barriers that present concerns regarding human effects include caltrops, concertina wires, webshots and entanglement grenades, tire spikes, and portable vehicle arresting barriers (PVABs). Caltrops and concertina wires are designed to deny pedestrian entry into an area by the obvious injury that will be incurred if entry is attempted. Webshots and entanglement grenades are designed to stop fleeing individuals by firing a net over them and entrapping them long enough for the pursuer to reach them. Tire spikes and PVABs are designed to stop fleeing vehicles, and injury may result if there is a crash or if the PVAB fails.

Mechanisms of Injury

Caltrops and concertina wires can cause lacerations and punctures, particularly to the extremities. The injuries are rarely unintended, unless an innocent civilian wanders into the restricted area at night and fails to notice the presence of the barriers. The injuries are not expected to be permanent, however, unless the individual is determined to break through the barrier. Webshots and entanglement grenades are not expected to cause major or permanent injuries unless the fugitive happens to hit his or her head on a hard surface during a fall. The probability of that happening is expected to be low. Other injuries can include twisted ankles and wrists and bruises and contusions, none of which is permanent. As for tire spikes, the only risk is the loss of control of the vehicle after the tires are blown, particularly if only one is blown. The vehicle may crash into some other barrier, injure nearby pedestrians, cyclists, or vehicular occupants, or roll over. It may also crash into a building, injuring its occupants. Thus, the site of deployment needs to be carefully selected. The risk of serious or fatal injury to the occupants of the fleeing vehicle also needs to be considered, especially since fugitives are not likely to use belted restraints. Fatalities can occur when unbelted occupants are ejected in a rollover. PVABs have been tested at 45 mph. A risk exists for head and neck injuries to unbelted occupants at that speed. The system has not been tested at higher speeds, and the resulting injuries are unknown but are expected to be more severe than at 45 mph. If there is failure of the PVAB system before arresting the vehicle, a crash may occur.

Recent and Current Studies

The injuries that can be caused by caltrops and concertina wires have not been studied. The obviousness of their injury potential does not justify any research. While webshots and entanglement grenades appear to present a very low probability of permanent injury, prevention of a severe head injury is nevertheless difficult in this situation and the state of the art in computer modeling of this event is currently unable to simulate human muscular response, particularly since it is totally unpredictable. The injury mechanisms involved in the use of tire spikes and PVABs are the same as those observed in automotive crashes. Unbelted occupants are more at risk than belted ones, regardless of whether the vehicle is equipped with airbags or not. The severity of the injury depends on the crash velocity and increases with older and smaller vehicles.

C.8 PSYCHOLOGICAL EFFECTS

The main purpose of NLWs is to change the behavior of opponents while minimizing collateral damage. For this reason, psychological and behavioral studies are an important adjunct to the development of NLWs. Studies should seek to understand the behavioral responses to NLWs and the psychological effects and effectiveness of these weapons.

An example of the kind of behavioral effects that are important to understand might be the response of a crowd to the use of VMADS. What might be the response of subjects caught in the VMADS beam with others close by? Given this information, techniques that it would be possible to develop would most likely cause people to move away from the target area as opposed to panicking. Similarly, it would be useful to have more understanding of the response of people from different cultures to specific malodorants and when exhibiting different levels of aggression.

Because NLWs are applied with the intent of clearing, dissuading, blocking, or otherwise causing peaceful changes in behavior, it is important to thoroughly understand people's responses to them and behaviors as individuals or in the context of the crowds and confined spaces likely to be encountered in missions.

Recent developments in broadening the bandwidth of RF generators and the development of systems capable of producing very short pulses and very high peak power provide a glimpse into the vast unexplored region of biological effects or human susceptibilities and potential avenues for NLWs. Single pulses of RF energy have been associated with stun and seizure, decreased spontaneous animal activity, microwave-induced whole body movements, thermal sensations, and startle modification. Some of these effects may be associated with the activation of specialized nerve endings and/or may be only partially mediated by heating. Little evidence has been identified to suggest that a bioelectromagnetics program exists to explore the vast domain of RF energy for application to NLWs.

The present VMADS system and those under development are based on knowledge initially gained decades ago. Leap-ahead non-lethal weapons technologies will require a much more thorough knowledge of RF interactions with the human body than is in existence or can be envisioned within the current programmatic plans of the JNLWD. Such an effort would require a prolonged effort by a multidisciplinary team of researchers skilled in a wide range of disciplines.

Likewise, to exploit lasers for use as NLWs to their maximum potential, specific programs would be required to evaluate the susceptibilities of humans to eye-safe light intensities. It will be necessary to understand the potential for visual disruption as a function of the photon wavelength, use of multiple wavelengths, pulse shapes, interexposure intervals, and the effects of cofactors.

The use of cofactors might be considered in the search for synergistic effects of directed-energy systems. Confusion, temporary memory, and additional stages of neural disruption might be assisted by the application of multiple stimuli, properly timed. The demonstrated psychological effects related to illuminating human targets in Somalia demonstrate the need for an accompanying psychological line of study.

The main purpose of any weapon is to change the behavior of an opponent. Given the non-lethal weapons goal of changing behavior while minimizing collateral damage, opportunities must be sought to understand how to optimize psychological effects toward change of behavior within the context of available and desired NLWs. Only cursory consideration is now given to the use of existing weapons systems for psychological advantage, but it seems within the realm of possibility that systems might be developed with that in mind.

Examples of psychological effects were identified in the preceding sections on specific health effects. Much opportunity seems possible using systems that are explicitly designed to enhance communication, since information exchange is a principal medium of psychological effects. Notable among these were the acoustic technologies that provide communication through vastly different means.

In addition to the intended targeting of psychological effects are the effects that might be associated with kinetic-energy, directed energy, or chemical systems. Often these are applied with the intent of clearing, dissuading, blocking, and so on. Unless these weapons systems are thoroughly studied in the context of crowds as well as of individuals in both open and confined spaces, there could easily be unintended consequences as a result of undesirable psychological responses.

D

Biographies of Committee Members and Staff

Miriam E. John is vice president for the California Division at Sandia National Laboratories. The principal programs of the division, located in Livermore, California, include nuclear weapons stewardship; weapons demilitarization; chemical/biological weapons defense; combustion and materials research; advanced lithography and microsystems development; microchemical/-biological and remote laser-based chemical detection; and distributed, secure, advanced computational and information systems. Dr. John has served in a number of managerial and technical roles for the laboratory in various areas including new program development; nuclear weapons development; systems analysis; thermal analysis/fluid mechanics research and development; experimental and theoretical studies in heterogeneous catalysis, thermodynamics, and multiphase reacting flow; and postdoctoral work in alternative energy concepts analysis and simulation. She has participated in numerous defense community efforts, including the Department of Defense's Threat Reduction Advisory Committee, the Defense Science Board's summer and task force studies, and the Air Force Scientific Advisory Board, as well as serving on the National Research Council's Board on Army Science and Technology. She is also a member of DOE's National Commission on Science and Security. Dr. John has served on the Advisory Board for the Department of Chemical Engineering at Princeton University and, more recently, on the Executive Advisory Committee for the National Science Foundation's Science and Technology Center for Environmentally Responsible Solvents and Processes at North Carolina State University/University of North Carolina. She is also a member of the Board of Directors of ANSER, Inc. She is currently a member of the Naval Studies Board. Dr. John was awarded her Ph.D. in chemical engineering from Princeton University in 1977.

John B. Alexander is an independent consultant in matters relating to non-lethal weapons technology, intelligence, and special operations. Currently he serves as an advisor to the Commander in Chief, U.S. Special Operations Command. Dr. Alexander entered the U.S. Army as a private in 1956 and rose through the ranks, retiring as a colonel in 1988. During his military career, he held many key positions in special operations, intelligence, and research and development. From 1966 through early 1969, he commanded Special Forces "A" Teams in Vietnam and Thailand; his last military assignment was as director, Advanced Systems Concepts Office, U.S. Army Laboratory Command. Subsequent to his retirement from the Army, Dr. Alexander joined Los Alamos National Laboratory, where he developed the concept of non-lethal defense. In addition to serving on numerous government and scientific advisory boards, Dr. Alexander organized and chaired the first five major conferences on non-lethal warfare, served as a U.S. delegate to four NATO studies on the topic, and has written extensively in the field. As a member of the first Council on Foreign Relations non-lethal warfare study, he was instrumental in influencing the report that is credited with causing the Department of Defense to create a formal non-lethal weapons policy in July 1996. Additionally, he served for 5 years as a deputy sheriff in Dade County, Florida. Dr. Alexander received an M.A. from Pepperdine University and his Ph.D. from Walden University; he attended the Kennedy School of Government general officer program, National and International Security for Senior Executives, at Harvard University.

Michael B. Berger is program director for energy and environment at the Logistics Management Institute (LMI), where he oversees research in fields of environment, energy management, and occupational health and safety. Mr. Berger has more than 15 years of experience performing and overseeing analyses related to national defense and federal management. Before joining LMI, he served in key staff positions at the Office of the Secretary of Defense, the U.S. Defense Conversion Commission, and the U.S. Congressional Budget Office (CBO). During his tenure at CBO, he was responsible for analyzing budget requirements for the U.S. Navy that related to weapons procurement issues. The products of his work included testimony before congressional committees and CBO reports on long-range budget requirements for the entire U.S. Navy, and on combat logistics ships, amphibious warfare ships, and tactical aircraft. Mr. Berger received his master's degree in public policy from the University of California at Berkeley.

Ruth A. David is president and chief executive officer at Analytic Services, Incorporated (ANSER), a not-for-profit public service research institute that provides solutions to national and international issues. Her background is in intelligence, surveillance, and reconnaissance technologies. Before joining ANSER, she was deputy director for science and technology at the Central Intelligence

Agency, where she had leadership responsibilities for supporting and improving the collection, processing, analysis, and dissemination of intelligence through the research, development, and application of technology. Previously, Dr. David served in several managerial positions at Sandia National Laboratories. Her technical experience includes digital and microprocessor-based system design, digital signal analysis, adaptive signal analysis, and systems engineering and integration. Dr. David is a member of the National Security Agency's Advisory Board, the Department of Energy's Nonproliferation and National Security Advisory Committee, the Defense Science Board, and the Senate Select Committee on Intelligence Technical Advisory Board; she is also a member of the Draper Corporation. She is currently a member of the Naval Studies Board. Dr. David was awarded her Ph.D. in electrical engineering from Stanford University in 1981.

Clay E. Easterly is the Oak Ridge National Laboratory's (ORNL's) leader for the Virtual Human Project. He was group leader of the Health Effects Group for the Chemical and Biological Physics Section at ORNL between 1987 and 2000, overseeing a research staff with formal training in toxicology, epidemiology, applied mathematics, physics, health physics, medical technology, ecology, and public health. A physicist by training, Dr. Easterly joined the ORNL technical staff in 1973, and since has maintained a long-term research focus in three primary areas: tritium oxidation and exchange, fusion health and safety, and non-ionizing electromagnetic fields. In particular, Dr. Easterly's research interests include the use of non-ionizing electromagnetic fields for the development of alternatives to lethal forces. He has served on numerous scientific and technical advisory boards, including Non-Lethal Defense III, sponsored by the National Defense Industrial Association, of which he was co-chair. Dr. Easterly was awarded his Ph.D. in physics from the University of Tennessee.

Milton Finger is retired deputy director, Department of Defense Programs Office, at Lawrence Livermore National Laboratory (LLNL). He graduated from the University of California at Berkeley with a B.S. degree in 1957 and has spent his entire career at LLNL, starting as a staff chemist in the Chemistry and Materials Science Division. Mr. Finger's areas of expertise are in defense science and technology; military operations and organization; technologies for peace operations, law enforcement, and operations other than war; humanitarian demining and countermine technologies; conventional weapons systems, including the areas of lethality and survivability; ordnance engineering; propellant chemistry; electronic combat; weapons effects; munitions target interactions; chemistry of explosives; hydrodynamics, detonation physics, explosives equations of state; explosives safety and initiation; high-speed optics and electronic diagnostics; computer simulation and prediction of high explosives performance; and intelligence assessments and emergency response teams. Mr. Finger is a lecturer on explosives to the San Francisco Bay Area Law Enforcement Community, Washington State University, and the Institute of American Bomb Technicians and Investigators. He is a member of several advisory boards, such as the U.S. Air Force Scientific Advisory Board and the Defense Science Board. He served with the Weapons Panel of the Technology for Naval Forces study completed in 1997 by the Naval Studies Board.

Charles A. Fowler, an independent consultant, is retired senior vice president at Mitre Corporation, a federally funded research and development center serving the government on issues relating to national security. Mr. Fowler, a member of the National Academy of Engineering, has an extensive background in electronic warfare, particularly in regard to military systems utilizing radar, sensor, and countermeasure technologies. Mr. Fowler began his career in 1942 as a staff member of the Radiation Laboratory at the Massachusetts Institute of Technology, where he participated in the development and testing of the ground controlled approach radar landing system. He later went on to engineering and management positions at the Raytheon Systems Company before joining Mitre in 1976. Mr. Fowler is a fellow of the American Institute of Aeronautics and Astronautics, as well as of the Institute of Electrical and Electronics Engineers. Mr. Fowler received his B.S. in electrical engineering from the University of Illinois in 1942.

Charles Higgs is assistant leader for laser and sensor applications at the Lincoln Laboratory of the Massachusetts Institute of Technology (MIT/LL). Research interests of Dr. Higgs, a physicist by training, include the application of lasers for non-lethal weapon technologies. At MIT/LL, he has conducted extensive research in laser radar for both imaging targets and atmospheric measurements, including the development of electro-optical systems, theoretical investigations of the basic physics of laser propagation, and experiments ranging from small-scale laboratory measurements to large-scale field measurements. Recent efforts include the use of adaptive optics for investigating atmospheric turbulence, and the employment of miniature sensors (i.e., microlasers) to measure environmental pollutants and biological substances. Dr. Higgs was awarded his Ph.D. in physics from Rice University.

Phil C. Houser is senior manager for advanced programs at Raytheon Company, Washington headquarters, where he provides technical and management support to the Office of the Secretary of Defense, Joint Chiefs of Staff, and the Services on low observables and counter-low-observable technologies and systems. Before joining Hughes Missile Systems Company (now Raytheon), Mr. Houser served as an F-16 instructor pilot and wing weapons officer in the U.S. Air Force. Since joining Raytheon as an engineer, he has held a wide range of management positions in the development and integration of advanced weapon and sensor systems. In addition to his professional accomplishments, Mr. Houser is a life member of the National Defense Industrial Association and an active member of the Association of Old Crows, American Defense Preparedness Association, and the Air Force Association. Mr. Houser earned his B.S. in electrical engineering at the U.S. Air Force Academy.

John W. Hutchinson is Gordon McKay Professor of Applied Mechanics at Harvard University. A member of the National Academy of Sciences and National Academy of Engineering, Dr. Hutchinson is a theoretician in the area of solid and structural mechanics, working broadly on problems arising within elasticity, plasticity, stability, and fracture. His major research contributions concern the buckling of shell structures, nonlinear fracture mechanics, and the micromechanics of polycrystalline materials and composites. In recent years, however, Dr. Hutchinson's primary research emphasis has been on the mechanics and micromechanics of thin films, coatings, and multilayers. Dr. Hutchinson has served on numerous scientific and advisory boards; he currently serves on the National Research Council's U.S. National Committee on Theoretical and Applied Mechanics. Dr. Hutchinson received his B.S. in applied mechanics from Lehigh University in 1960 and his M.S. and Ph.D. from Harvard University in 1961 and 1963, respectively.

Albert I. King is distinguished professor of mechanical engineering and director of the Bioengineering Center at Wayne State University. He also serves as adjunct professor of orthopedics and is an associate in neurosurgery. A member of the National Academy of Engineering, Dr. King has expertise in understanding the mechanism, response, and tolerance of the human body to normal and traumatic loading. His research interests are in areas primarily relating to trauma biomechanics, such as the effects resulting from automotive collisions. In addition, his research interests have included the computer modeling of the brain's response to blunt head impact, as well as the thoracic response to impact from non-lethal weapons. His professional society memberships include those in the American Society of Mechanical Engineers (fellow), the American Academy of Orthopedic Surgeons (associate member), the American Society of Biomechanics (member), and the Association for the Advancement of Automotive Medicine (member). Dr. King was awarded his Ph.D. from Wayne State University.

Annette J. Krygiel is an independent consultant. She recently completed an assignment as a visiting fellow at the Institute for National Strategic Studies at the National Defense University, where she wrote a book on large-scale system integration. Dr. Krygiel's expertise is in the management of large-scale systems, particularly in regard to software development. Before being appointed to the Institute for National Strategic Studies, she was director of the Central Imagery Office (CIO), a Department of Defense combat support agency. She remained the director for 27 months, until CIO joined the National Imagery and Mapping

Agency in October 1996. Dr. Krygiel began her career at the Defense Mapping Agency, where she held various positions such as chief scientist. She has been a participant in National Research Council studies, including that of the Panel on Distributed Geolibraries: Spatial Information Resources and the Committee on Network-Centric Naval Forces. She is currently a member of the Naval Studies Board. Dr. Krygiel was awarded her Ph.D. in computer science from Washington University at St. Louis.

James W. Meyer is retired senior vice president, director of research and development/chief technical officer at the Eastman Kodak Company. Dr. Meyer is a chemist by training, and his career at Kodak included research on novel color imaging systems, fundamental studies of image structure and color reproduction, and pioneering work on one-time-use cameras. In addition, he led laboratory efforts in optical and magnetic recording technologies, electronic materials, and novel manufacturing technology. Since retiring from Kodak in 1998, Dr. Meyer created and has led the Technical Advisory Group for the Rochester Museum and Science Center. In addition to serving as chairman of the board of trustees for the Rochester Museum and Science Center, he is a member of the American Chemical Society, the American Association for the Advancement of Science, the Society for Imaging Science and Technology, and the Materials Research Institute. Dr. Meyer holds a B.S. degree in chemistry from the University of Wisconsin and a Ph.D. in physical organic chemistry from the California Institute of Technology. He did postdoctoral work in metal-organic chemistry at Stanford University.

Robert B. Oakley is distinguished visiting fellow at the Institute for National Strategic Studies at the National Defense University, where he has been since 1995. Ambassador Oakley retired from the U.S. Foreign Service in 1991, after 34 years of service. His principal assignments included Khartoum, Sudan, followed by the Office of United Nations Political Affairs of the Department of State; subsequent posts included Abidjan, Ivory Coast; Saigon, Vietnam; Paris, France; the U.S. Mission to the United Nations; and Beirut, Lebanon. Ambassador Oakley became Deputy to the Assistant Secretary of State for East Asia and Pacific Affairs in January 1977, and was then posted to Zaire in November 1979, and later to Somalia, as the U.S. ambassador. He was appointed director of the State Department Office of Combating Terrorism in 1984. Before joining the National Security Council staff as assistant to the president for the Middle East and South Asia in January 1987, Ambassador Oakley became a fellow at the Carnegie Endowment for International Peace from September to December 1986. After his retirement as ambassador to Pakistan in September 1991, he became associated with the U.S. Institute of Peace as a coordinator of the Special Program in Middle East Peacekeeping and Conflict Resolution. He is currently a member of the Naval Studies Board. Ambassador Oakley earned a B.A. in philosophy and history from Princeton University in 1952.

Steven H. Scott is manager for the Access Delay Technology Department at Sandia National Laboratories, where he oversees research, engineering development, and the application of barrier designs and activated dispensable materials for access delay applications. Mr. Scott's expertise is in non-lethal technologies and their applications. His current research interests include the physical characterization, security effectiveness, material longevity, and toxicology and environmental analyses of activated dispensable materials, including those developed and used for safeguard applications (i.e., polyurethane foams, sticky thermoplastic foams, stabilized aqueous foams, chemical smoke, pyrotechnic smoke, entanglements and deployable barriers, and chemical irritants). Mr. Scott received his master's degree in nuclear engineering from the University of Michigan.

William M. Tolles is retired associate director of research for strategic planning at the Naval Research Laboratory (NRL), Washington, D.C. Currently an independent consultant and an advisor to academic research centers internationally, Dr. Tolles has expertise in state of the science and technology assessments in nanostructured materials. A chemist by training, he joined the faculty of the Naval Postgraduate School in 1962; he later served there as an assistant, associate, and full professor of chemistry (1962-1984). He also served as the dean of research and dean of science and engineering (1977-1984) at the Naval Postgraduate School before being appointed superintendent of the Chemistry Division at NRL in Washington, D.C. In 1989 he assumed his position at NRL, until his retirement in 1995. Dr. Tolles's research interests include nanoscience, microelectromechanical systems, nonlinear optical spectroscopy, microwave properties of materials, molecular spectroscopy, molecular orbital calculations, microwave spectroscopy, and electron spin resonance. Dr. Tolles was awarded his Ph.D. in chemistry from the University of California at Berkeley.

Paul K. Van Riper retired from the U.S. Marine Corps as a lieutenant general in 1997, after 41 years of active and reserve service. He is currently a private consultant and a member of several defense-related advisory boards, participating in a wide array of defense and security-related seminars, conferences, and studies. General Van Riper's long and distinguished military career included command of ground combat units; he is familiar with all aspects of Marine Corps operations. Several of his career highlights include being the first president of the Marine Corps University; Deputy Commander for Training and Education; Assistant Chief of Staff, Command, Control, Communications, and Computers; Director of Intelligence, Headquarters Marine Corps; and Commanding General, Second Marine Division. Before his retirement, General Van Riper served as Commanding General, Marine Corps Combat Development Command. He was also a member of the Naval Studies Board. General Van Riper graduated from California State University with a B.A. degree, entered the 34th Officer Candidate Course, and was commissioned a second lieutenant in 1963. General Van

Riper is also a graduate of the College of Naval Command and Staff at the Naval War College and the Army War College.

Staff

Charles F. Draper is a senior program officer at the National Research Council's (NRC's) Naval Studies Board. Before joining the NRC in 1997, Dr. Draper was the lead mechanical engineer at S.T. Research Corporation, where he provided technical and program management support for satellite earth station and small satellite design. He received his Ph.D. in mechanical engineering from Vanderbilt University in 1995; his doctoral research was conducted at the Naval Research Laboratory, where he used an atomic force microscope to measure the nanomechanical properties of thin film materials. In parallel with his duties as a graduate student, Dr. Draper was a mechanical engineer with Geo-Centers, Incorporated, working onsite at NRL on the development of an underwater x-ray backscattering tomography system used for the non-destructive evaluation of U.S. Navy sonar domes on surface ships.

Ronald D. Taylor has been the director of the Naval Studies Board of the National Research Council (NRC) since 1995. He joined the NRC in 1990 as a program officer with the Board on Physics and Astronomy and in 1994 he became associate director of the Naval Studies Board. During his tenure at the NRC, Dr. Taylor has overseen the initiation and production of more than 40 studies focused on the application of science and technology to problems of national interest. Many of these studies address national security and national defense issues. From 1984 to 1990, Dr. Taylor was a research staff scientist with Berkeley Research Associates, working onsite at the Naval Research Laboratory on projects related to the development and application of charged particle beams. Before 1984, he held both teaching and research positions in several academic institutions, including those of assistant professor of physics at Villanova University, research associate in chemistry at the University of Toronto, and instructor of physics at Embry-Riddle Aeronautical University. Dr. Taylor holds a B.S. in physics from Johns Hopkins University, and an M.S. and a Ph.D. in physics from the College of William and Mary. In addition to science policy, Dr. Taylor's scientific and technical expertise is in the areas of atomic and molecular collision theory, chemical dynamics, and atomic processes in plasmas. He has authored or co-authored nearly 30 professional scientific papers or technical reports and given more than two dozen contributed or invited papers at scientific meetings.

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Acronyms and Abbreviations

ABL	airborne laser
ACTD	advanced concept technology demonstration
AD	area denial
AFRL	Air Force Research Laboratory
Ar	argon
ATD	advanced technology demonstration
AT/FP	antiterrorism/force protection
ATL	advanced tactical laser
BAA	broad area announcement
BDA	battle damage assessment
BOSS	battlefield optical surveillance system
C2	command and control
CAPS	coastal area protection system
CCI	command capability issue
CEP	concept exploration program
CETO	Center for Emerging Threats and Opportunities
CFACCEP	clear facilities concept exploration program
CFR	Council on Foreign Relations
CINC	commander in chief
CLADS	canister-launched area denial system
CLF	combat logistics forces
CM	diphenylamine arsenic chloride
CN	chloroacetophenone

CNO	Chief of Naval Operations
COE	center of excellence
COIL	chemical oxygen iodine laser
CONOPS	concept of operations
COTS	commercial off-the-shelf
CPR	cardio-pulmonary resuscitation
CRD	capstone requirements document
CS	o-chlorobenzylidene malononitrile (tear gas)
CSIS	Center for Strategic and International Studies
CSL	Commander, Submarine Force, Atlantic Fleet
CWC	Chemical Weapons Convention
CWL	Chemical Warfare Convention
DARPA	Defense Advanced Research Projects Agency
DEW	directed-energy weapon
DF	deuterium-fluoride
DF/HF	deuterium-fluoride/hydrogen-fluoride
DOD	Department of Defense
DOE	Department of Energy
DPB	deployable pursuit boat
DTRA	Defense Threat Reduction Agency
EBACS	electronic badge/access control system
ECBC	Edgewood Chemical and Biological Command
EMP	electromagnetic pulse
ERGM	extended-range guided munition
ESB	exhaust stack blocker
ESS	electronic security system
EW	electronic warfare
FASM	forward air support munition
FLIR	forward-looking infrared
FNC	future naval capability
FYDP	future year defense program
GOTS	government off-the-shelf
GPS	Global Positioning System
GVS	ground vehicle stopper
HALT	hinder adversaries with less-than-lethal technology
HEAP	Human Effects Advisory Panel
HECOE	Human Effects Center of Excellence
HEL	high-energy laser

HEPAT	Human Effects Process Action Team
HERB	Human Effects Review Board
HICAP	high capacity artillery projectile
HMMWV	highly mobile multipurpose wheeled vehicle
HPM	high-power microwave
HQMC	Headquarters, U.S. Marine Corps
INEEL OLETC	Idaho National Engineering and Environmental Laboratory, Office of Law Enforcement Technology Commercialization
IOC	initial operational capability
IPT	integrated product team
IR	infrared
JCATS	joint conflict and tactical simulation
JCIDO	Joint Combat Identification Office
JCIG	joint coordination and integration group
JCS	Joint Chiefs of Staff
JFC	joint force commander
JFCOM	Joint Forces Command
JIATF-E	Joint Inter-Agency Task Force-East
JIATF-W	Joint Inter-Agency Task Force-West
JMAA	joint mission area analysis
JNLWD	Joint Non-Lethal Weapons Directorate
JROC	Joint Requirements Oversight Council
JSOW	joint standoff weapon
KE	kinetic energy
LEWK	loitering electronic warfare killer
LIGA	Lithographie, Galvanoformung und Abformung
LLNL	Lawrence Livermore National Laboratory
LOCAAS	low cost autonomous attack system
LOE	limited-objective experiment
LTA	limited technology assessment
MAIS	major automated information systems
MASSAF	maritime ships security augmentation force
MAV	micro air vehicle
MCM	mine countermeasures
MCCM	modular crowd control munition
MCWL	Marine Corps Warfighting Laboratory
MDAP	major defense acquisition program

MEMS	microelectromechanical system
MMCM	modular crowd control munition
MNS	mission needs statement
MOA	memorandum of agreement
MOOTW	military operations other than war
MOUT	military operations in urban terrain
MTBI	mild trauma brain injury
MTW	major theater war
NAVSEASYSCOM	Naval Sea Systems Command
Nd:YAG	neodymium:yttrium aluminum garnet
NEMP	non-lethal electromagnetic pulser
NGO	non-governmental organization
NIJ	National Institute of Justice
NLDEWS	non-lethal directed-energy barrier system
NLD IV	Non-Lethal Defense Conference IV
NLRF	non-lethal rigid foam
NLW	non-lethal weapon
NOOTW-TC	Naval Operations Other Than War-Technical Center
NRL	Naval Research Laboratory
NSC	National Security Council
NSWC	Naval Surface Warfare Center
NSWCDD	Naval Surface Warfare Center, Dahlgren Division
NVA	North Vietnamese Army
OC	oleoresin capsicum (in pepper spray)
OCONUS	outside (the) continental United States
OD	optical density
OICW	objective individual combat weapon
OLDS	overhead liquid dispersal systems
ONR	Office of Naval Research
OOTW	operations other than war
OPNAV	Office of the Chief of Naval Operations
OPTION	OC optional round for USMC service weapon
ORD	operational requirement document
OSD	Office of the Secretary of Defense
OS&T/ARL	Office of Science and Technology, Army Research Laboratory
PEP	pulsed-energy projectile
PIKL	pulsed impulsive kill laser
POM	program objective memorandum
PVAB	portable vehicle arresting barrier

PVC	polyvinyl chloride
PWC	personal watercraft
RCA	riot control agent
R&D	research and development
RDA	research, development, and acquisition
RDT&E	research, development, testing, and evaluation
RESS	regional electronic security system
RF	radio frequency
RGES	running gear entanglement system
RHIB	rubber hull inflatable boat
ROE	rules of engagement
SAB	Scientific Advisory Board (Air Force)
SASO	Southeast Asia Support Organization
SBIR	Small Business Innovation Research (program)
SDV	swimmer delivery vehicle
SEAL	sea, air, land (team)
SECNAV	Secretary of the Navy
SRDC	Systems Research and Development Corporation
SSC	small-scale contingency
SSG	Strategic Studies Group
S&T	science and technology
SULNT	small unit leaders non-lethal trainer
T&E	testing and evaluation
TF	task force
THEL	theater high-energy laser
TIP	technology investment program
TSWG	technical support working group
UAV	unmanned aerial vehicle
UGV	unmanned ground vehicle
UN	United Nations
USAREUR	U.S. Army Europe
USAFRL	U.S. Air Force Research Laboratory
USCG	U.S. Coast Guard
USD (A&T)	Under Secretary of Defense (Acquisition and Technology)
USMCSC	U.S. Marine Corps Systems Command
USNC	U.S. Naval Forces, Central Command
UUV	unmanned underwater vehicle
UV	ultraviolet

VC	viscous criterion
VCNO	Vice Chief of Naval Operations
VF	ventricular fibrillation
VMADS	vehicle-mounted active denial system
WBS	waterside barrier system
WMD	weapon of mass destruction
WSESRB	Weapon System Explosives Safety Review Board
WSS	waterside security system