Biological Effects of Non-Lethal Weapons: Issues and Solutions

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1. Introduction

Military peace keeping, humanitarian efforts, and missions other-than-war have become increasingly common. In such operations, many dangers exist to the troops, yet the use of lethal force is often not justified or acceptable. This conference in concerned with new non-lethal options for applying military force.

This new requirement has been addressed by the United States Department of Defense in a policy statement for Non-Lethal Weapons (NLWs), in which such weapons are defined as "**weapon systems** explicitly designed to **incapacitate personnel** or materiel while **minimizing fatalities, permanent injury, and undesired damage to property and the environment**" (DoD Policy Directive 3000.3). The development and fielding of new weapons that fit this definition will require much work using many approaches. I will focus on the biological effects of NLWs.

a. What are bioeffects?

Broadly, bioeffects include any effect an internal or external stimulus has on part or all of a biological organism. A random sample includes: DNA damage, depolarization of an excitable membrane, muscular contraction, loss of equilibrium, sensory stimulation, sensory blocking, emotional response, nausea, fear, increase in heart rate, avoidance, cellular damage, altered metabolism, confusion, loss of consciousness, convulsions, death. Bioeffects can be as simple and hard to detect as the ionization of a biomolecule, such as DNA, or as complex and obvious as a grand mal seizure. They can be as innocuous as a recognition of a pleasant scent or as harmful as stopping of the heart & death. In fact, as living human beings almost all that we are and all that we will become is determined by bioeffects.

b. Who are bioeffects specialists?

Bioeffects specialists include medical doctors, physiologists, psychologists, behavioral scientists, veterinarians, anatomists, neuroscientists, biologists, epidemiologists, theoreticians and others, all concerned with the effects of any stimulus (biological, chemical, or physical) on part of all of a biological organism.

2. How are bioeffects important to NLWs?

DoD Policy Directive 3000.3 on policy for NLWs provides three general requirements for a satisfactory NLWs program: Technical feasibility, operational utility, and policy acceptability. Bioeffects form part of the foundation for meeting each of these requirements.

a. Technical Feasibility

Technical feasibility means that the science, engineering, and manufacturing capability exist to build a desired non-lethal system. Issues of cost, size, weight, logistics, and maintenance predominate. Bioeffects are involved in providing the requirement parameters for the system. In an orderly process, bioeffects review and research would: (1) determine areas of human vulnerability; (2) develop biological criteria for biological effects on the target, recovery of the target, and long-term medical impact on targets, operators, and bystanders; and then (3) provide data to the engineers so that a system can be built to optimally expose the target and limit collateral damage. Too often, the process is anything but orderly, and NLW systems are built on the minimally supported belief or hope that if you make it hard enough, bright enough, loud enough, smelly enough, etc., it must do something. For anti-material NLWs, it is often overlooked that these weapons could also impact humans who are operators of the weapons, are using the material being destroyed, or are merely bystanders.

b. Operational Utility

Operational utility refers to the usefulness of the NLW, and, in the context of bioeffects, only applies to anti-personnel NLWs. The important question here is "What do commanders and military troops consider to be useful bioeffects?" In the short list I provided earlier, some of bioeffects are too minimal to be useful and others to extreme, but where do you draw the line. DoD Policy Directive 3000.3 refers to "incapacitation" as a goal of NLWs; but, what does this actually mean? Some might consider "incapacitation" to include a disinclination to perform a task (such as throw a rock or enter a forbidden area), whereas others may consider "incapacitation" to mean the impossibility of performing any task. The only U.S. military definition of "incapacitation" that I have found comes from the Joint Service Manual for NLW Tactics, Techniques, and Procedures and states:

> "Incapacitation is achieved when weapons effects result in physical inability (real or perceived) or mental disinclination to act in a hostile or threatening manner. In keeping with the guiding principles of NLWs, this incapacitation should be readily reversible; preferably, self-reversing through the passage of time."

In addition to achieving a non-lethal goal, i.e., incapacitation, operational commanders are also interested in the parameters of the incapacitation. Some relevant parameters include: dose for main desired effect; can the effect be tuned; time until initial effect; duration of effect; synergy with other factors; reversibility versus irreversibility of effects; side-effects to targets; undesired collateral effects; environmental effects; and susceptibility to countermeasures.

Bioeffects analysis by review, research, and modeling is important to addressing all of these parameters.

An extremely important point is that bioeffects specialists need to communicate with the military commanders and operators who define "Operational Utility" by setting the parameters and criteria for a "useful" NLW. There is a vast number of possible bioeffects and parameters of bioeffects for proposed NLWs. Bioeffects specialists cannot test them all; they need interaction with the operators to help focus their efforts on useful bioeffects and parameter criteria.

c. Policy Acceptability

The third requirement for an acceptable NLW is Policy Acceptability. This is an extremely complicated topic in which bioeffects have two major roles. For anti-personnel NLWs, the policy that NLWs should "minimize permanent injury" is primarily a bioeffects issue. The immediate effects of an NLW are part of its evaluation as having operational utility, but the time to and extent of recovery from the weapon's effects are important criteria to determine policy acceptability. To illustrate that bioeffects issues can be "show-stopper", one only need remember that the Laser Countermeasures Systems (LCMS) Program was cancelled in 1995, just as it was about to go into production, because of the bioeffects issue of eye-damage and blinding. Will the use of proposed acoustic NLWs be similarly limited because of concern over the possibility of ear damage or deafening?

The second role of bioeffects in NLW policy setting, concerns the long-term medical consequences of exposure to the NLWs for anyone exposed, including the operator, the target, and bystanders. If occupational exposure standards exist for the particular agent being used, as they do for many types of noise, radiation, and chemicals, then these standards can be followed, at least for operators and non-combatants. If the exposures are sufficiently novel that no health standards exist, for example certain types of directed energy, then standards need to be developed. Possible delayed effects, such as cancer, neural, or reproductive consequences need to be considered, if we are to minimize future litigation and public outrage. For example, one of the chemical components of sticky foam, butadiene, has been shown to cause cancer in animals; it is claimed that short term exposure to humans is not hazardous, but have sufficient bioeffects studies been done to assure policy acceptability? These concerns are relevant to anti-material technologies as well as anti-personnel application of NLWs

3. The Variability of Human Responses and the Probabilistic Nature of Bioeffects

a. Biological Variability and the Safety Margin

Because of biological variability there will always be uncertainty in predicting the biological responses to NLWs. Even among a consistent population of humans, such as a group of young adult males, there will be a variability in responses to the same stimulus. When the variance of the population increases, for example by adding persons of differing sizes, ages, weights, frailty, health, and both sexes, so will the variability of the population response to most NLWs. Within the context of this variability, the probability of different responses can be

estimated for different amounts or doses of the applied energy or chemical. The difference in dose required to produce a desired effects (e.g., incapacitation) and an undesired effects (e.g., permanent injury) is often called a safety margin. For an NLW with a good safety margin, the dose that produces the desired effect in most people would produce the undesired effect in none. A poor safety margin results if a particular dose produces both desired and undesired effects. The principles of such considerations are well developed in the disciplines of pharmacology and toxicology.

Therefore, biological responses to non-lethal weapons will be probabilistic at best and may be extremely uncertain. This fact is true for target, operator, and bystander effects. One of the roles of bioeffects specialists is to estimate "dose response" curves for proposed NLWs, so they can be used to access operational utility and policy acceptably of the NLW before acquisition and deployment.

b. Other Sources of Variability

Although it is true that bioeffects can be variable, it should be noted that they are not the only source of variability in the use of a NLWs. The amount of energy or chemical emitted from the weapon itself can be variable because of manufacturing differences, improper maintenance, and operator error or choice. The transmission of the energy from the weapon to the target is affected by variations in aiming, beam spread, and intervening conditions such as rain, wind, temperature, terrain, and structures. Coupling of the energy to the target can be passively affected by the target's size, orientation, and clothing as well as by active countermeasures purposively employed by the target. All of these factors affect the actual does delivered to the target and precede the biological variability and probabilistic nature of response, described above.

c. Remote Vital Signs Monitor: One approach to reducing the variability

In addition to conducting research to estimate the uncertainty in the biological effects of NLWs, another goal is to reduce the uncertainty. For maximal effectiveness and safety, an assessment of the desired effect should be available. Is a fallen adversary faking, incapacitated, unconscious, or already dead? For human targets some type of monitor to remotely determine vital signs (heart rate, respiration) would be useful. Controlling the application of the NLW energy on the target could be a key to insuring that the weapon produces its desired effect, yet does not pose too high a risk of causing lethality or permanent injury. Such devices are available, at least in brass board configurations, and should be developed as fieldable systems.

4. Approaches to Bioeffects Testing: Issues and Examples

In the first part of this paper, I have described the general importance of bioeffects to meeting the requirements for NLWs. In order to create validated models for effectiveness, recovery, and health consequences, the full range of techniques for the study of biological effects will be needed. Many of the needed techniques are fairly standard in the medical world. However, the nature of some of the non-lethal technologies make such assessments more complicated, requiring special facilities and equipment. I will give two types of examples of

approaches taken to study NLW bioeffects, one dealing with acoustics for anti-personnel NLWs and one dealing with ultrawideband radiation for anti-material applications.

a. Investigating the Non-Lethal Weapon Potential of Acoustic Energy

Historically, acoustic energy is reported in the Old Testament as having an anti-materiel effect on the walls of Jerico, but it was hardly a non-lethal use of acoustics, since the walls "came tumbling down" and everything in the city was "utterly destroyed". In his work "Life of Marcus Crassus", Plutarch described the use of bells and drums as a psychological NLW. More recently, Rock Music was used to annoy Manuel Noreigea in Panama. But despite its supposed historical roots and the attention it has received in recent articles in the popular media, there is very little scientific research on the usability of acoustics as an NLW. Research on acoustics at Brooks AFB has been sponsored by the Defense Advanced Research Projects Agency (DARPA) and by the U.S. Army's Armaments Research and Development Engineering Center (ARDEC).

Current ideas for NLWs using acoustics employ neither trumpets, drums, bells, or boom boxes. One idea is to use high intensity infrasound. Obtaining sources on which to conduct research is one of the biggest problems of NLW bioeffects testing. For initial work, we were forced to borrow an enormous acoustic test device developed by the Army Research Laboratory for environmental research. In order to abide by animal use regulations, our team moved a trailer based mobile laboratory to the desert location of the source. A team of 10 scientists traveled to the site, bringing research animals and instrumentation. The conditions were rather difficult, but excellent data were obtained.

Since there were no suitable indoor infrasound test facilities that would allow the testing of animals, we constructed a special pressure chamber, named the infrasound test device (ITS), in which we could examine the effects of infrasound at different frequencies on both anesthetized and awake subjects under controlled condition. A combination of field and laboratory studies, using different equipment, are also used to test other frequencies of sound.

The procedures used to test infrasound illustrate one of the main problems of bioeffects testing of NLWs. Especially for directed energy NLWs, the actual sources being developed for field use are often too e.g. hazardous and/or unreliable to be brought into the laboratory for systematic, controlled bioeffects testing. Doing a limited amount of science in the field is possible, but far too expensive to collect the extensive data needed for answering effectiveness, recovery, and health questions required for NLW bioeffects research.

With regard to acoustics, the primary health and safety issue relates to possible hearing damage of the target. For this reason, we do hearing tests on our animal subjects before and after acoustic exposures and, if there are indications of hearing threshold shift, for several weeks following the exposure

b. Investigating the Health Hazards of a Proposed Anti-Materiel NLWs

Many laboratories have reported developing electromagnetic weapons to disrupt

electronics, including stopping vehicles with electronic ignitions. In particular pulsed high-power microwaves (HPM) and ultrawideband (UWB) radiation are being considered. These "anti-material" weapons would most likely be used on systems that were being operated by personnel and so human exposures would be inevitable. Thus the possible health consequences to both the operator of the weapon and the people in the vicinity of the target are important issues.

Biological research on both UWB and HPM requires access to RF sources, and, as with acoustical research, while some research is conducted in the bioeffects laboratory using specifically designed lab sources, some must be conducted at the engineering laboratories were the sources are being developed. Thus, again our mobile lab is required. UWB bioeffects research started in 1991 and, because this type of radiation had never been tested before, we did a variety of quick tests to look for any dramatic effects. We found none, so developed a plan to examine the possibility of more subtle effects of UWB. The U. S. Army and Air Force research teams have completed studies on behavioral responses, cardiovascular effects, carcinogenicity potential, and induction of birth defects. A life time cancer promotion study and research on neurophysiological effects are still in progress. This work has been conducted on cellular and animal models ranging from bacteria, to yeast, to rats, to primates. To protect the people working with UWB, who are mainly employees of military establishments, the Tri-Service Electromagnetic Radiation Panel has issued an interim safety guidance for permissible exposure to UWB.

Most of the agents being considered for NLWs have been around for awhile and have already been subjected to extensive bioeffects analysis. However, other novel energies or chemicals may require a similar extensive analysis to that which I have described here for UWB.

5. Extrapolation from Animal to Human

The work on acoustics and UWB radiation at Brooks AFB currently exclusively uses animals. The use of animal models can provide general insight into the type of effects to be expected in humans, indications for thresholds and limits for effects in humans, and an understanding of the mechanisms of the effects; but, the question always remains of how well research using an animal model extrapolates to the human condition. Obviously, the best test subject is the human. Human use requirements are extremely strict, requiring multiple levels of review and approval as well as informed consent of the subject, but the insight provided from a carefully done human experiment can be well worth the trouble and risk and can provide the link that will allow math models to be developed and animal data to be extrapolated to humans with much greater predictive accuracy. Ultimately, experience from actual use of NLWs will provide information that will help improve the weapons themselves, as well as validate the models for future development.

6. Conclusion

Bioeffects specialists do not build weapons systems, they do not make policy, set rules of engagement, or pull the trigger during a conflict. However, they can provide information that will allow developers, policy makers, and operational commanders make better informed decisions

about the human impact of non-lethal weapons. Insufficient attention to bioeffects could lead to the development of expensive hardware that would be operationally useless, prohibited by policy, or both. Insufficient attention to bioeffects could lead to NLWs that produce unreliable or extremely variable effects. Inattention to bioeffects could also result in NLWs that too often produce irreversible damage to the target, and have long-term health consequences on the target, the operator, and bystanders. Considering these issues from an early stage of NLW development and including bioeffects specialists as partners on the NLW team will help assure the fielding of effective, safe, and acceptable new non-lethal weapons for military and law enforcement applications.

[1]DISCLAIMER: The opinions expressed in this paper are the author's and should not be interpreted as an official position of the U.S. Government.

[2]*Although no unpublished data are presented in this paper, it is noted that all animal research at the Air Force Research Lab... accomplished in accordance with approved protocols under "The Federal Animal Welfare Act PL 89-544; DOD Directive 3216 dated 17 Apr 95, Use of Animals in DoD Programs; and AFR 169-2, Use of Animals in DoD Programs" as implemented in Armstrong Laboratory AL Investigatory Handbook, dated 19 Oct 95, and all human research in accordance with approved protocols under AFI 40-402 "Using Human Subjects in RDT&E" as implemented in the Armstrong Laboratory Handbook for Investigators Involved in Human Experimentation, 40-1, May 95.)*

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