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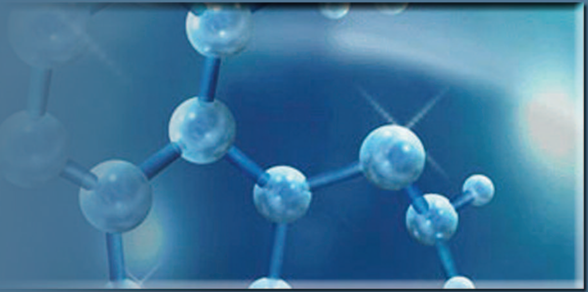

Analysis of Alternatives to Hexavalent Chromium

Professionals Plug Away in Effort to Keep IEEE 45 Current

Variable Velocity, Non-Lethal Ballistic Weapons, Part II

Volume 1, Number 2
September 2012

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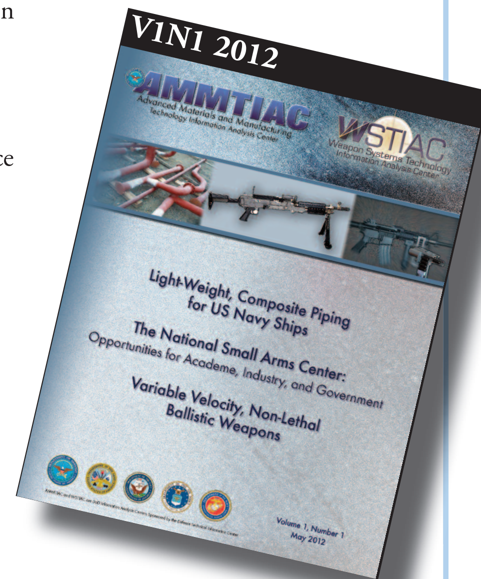

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The AMMTIAC-WSTIAC Journal *is a joint publication from the Advanced Materials, Manufacturing, and Testing Information Analysis Center (AMMTIAC) and Weapon Systems Technology Information Analysis Center (WSTIAC). AMMTIAC and WSTIAC are DoD-sponsored Information Analysis Centers, administratively managed by the Defense Technical Information Center (DTIC) and operated by Alion Science and Technology. All data and information herein reported are believed to be reliable; however, no warrant, expressed or implied, is to be construed as to the accuracy or the completeness of the information presented. The views, opinions, and findings contained in this publication are those of the author(s) and should not be construed as an official Agency position, policy, or decision, unless so designated by other official documentation. The appearance of an advertisement, announcement, product/service review, or article in the* AMMTIAC-WSTIAC Journal *does not constitute endorsement by the DoD or Alion Science and Technology. The* AMMTIAC-WSTIAC Journal *is distributed to more than 15,000 defense technology professionals around the world.*

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Analysis of Alternatives to Hexavalent Chromium:

A Program Management Guide to Minimize the Use of CrVI in Military Systems

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Report Preview

This article is excerpted from a recently published AMMTIAC report on the analysis of alternatives to using corrosion preventatives containing hexavalent chromium. In the area of corrosion prevention and control, AMMTIAC serves as the DoD's central source of engineering and technical data; as well as research and development information on metals, ceramics, polymers and composites. AMMTIAC is a charter member of the Corrosion Prevention and Control Integrated Product Team (CPC IPT) under the Office of Corrosion Policy and Oversight (CPO), and AMMTIAC has supported the CPO's mission since it was stood up in 2003. In addition to this publication, AMMTIAC has authored the handbook, Corrosion Prevention and Control: A Program Management Guide for Selecting Materials*, constructed a corrosion literature database containing nearly 9,000 publicly released documents available online, and has performed additional projects in corrosion prevention.*

INTRODUCTION AND BACKGROUND

Protecting the Nation's weapon systems and military infrastructure from the scourges of corrosion is a constant and ongoing challenge. For many decades, the "Gold Standard" in corrosion prevention and control has been the use of preventative compounds containing chromates, specifically those formulated from Hexavalent Chromium, which is also commonly referred to as CrVI. CrVI-based compounds have a long history of success in protecting durable assets, both in industry and in the DoD, and there is an extensive knowledgebase on these compounds from decades of judicious application. While an industry staple, CrVI is, however, a known carcinogen which can pose serious health and safety risks to workers and also adversely impact the environment. In recent years, the Environmental Protection Agency (EPA) and the Occupational Safety and health Administration (OSHA) have enacted stricter regulations, forcing reductions in its use. New military policy memoranda have called for minimizing CrVI use, as a consequence of stricter US and European regulations on human exposure and environmental contamination. It is important to point out that these policy memoranda are NOT a ban against using CrVI. However, a waiver is now required for any new use of CrVI in the Department of Defense. Alternative materials have been developed for some applications, with many more potential compounds still in development. However, none of the existing alternatives perform as well or as economically as CrVI. Thus, the use of alternatives brings risk to program managers who must meet performance, cost, schedule, and safety requirements. Program offices are left with the daunting and unenviable task of minimizing the use of CrVI without significantly impacting program objectives. PMs and their staffs would benefit most by instituting a regimented approach to evaluate candidate alternative materials for the particular component/system at hand; only using CrVI in cases where no alternative is adequate for the given application. This structured approach will need to be documented and will form the justification required for the Defense Acquisition Board (DAB). PMs do have technical authorities within their respective Services for guidance, as well as the OSD Office of Corrosion Policy and Oversight to help with this monumental task. AMMTIAC's guidebook presents the impacts associated with implementing alternatives, along with a decision flow chart process, to aid program managers and their staff in deciding when and where to use CrVI versus alternatives. It also covers resources available to PMs and the necessary measures program managers need to obtain a waiver to use CrVI.

> CrVI is the "Gold Standard" material in corrosion

> CrVI is also a strong carcinogen. The Services are directed to minimize its use

> CrVI has NOT been banned, but its minimization is encouraged by policy

Designing corrosion resistance into new systems upfront, early in the acquisition phase, will lead to lower life cycle costs (LCCs), resulting in more effective corrosion management, also with increased system safety and availability. The Defense Science Board (DSB) has determined that a 30% cost avoidance can be achieved in military systems by incorporating corrosion engineering principles in the design of new systems.[1]

Spending more funds up front to account for corrosion and degradation of systems will pay off over time. There will likely be trade-offs in performance versus corrosion resistance; but if those trade-offs are known in the acquisition phase, a corrosion prevention and control strategy that reflect balanced priorities may be implemented to properly manage and minimize corrosion, whatever the chosen path.

> PMs must weigh alternatives to CrVI, but must do so carefully and thoroughly

THE DILEMMA OF HEXAVALENT CHROME

The controversy surrounding CrVI is emblematic of the larger issue of balancing the Defense needs of the Nation against the desire for a cleaner environment and a safer workplace. The two aims, while not necessarily opposites, are exclusive of one another, and on many occasions, the drive to meet one aim is contrary to meeting the other. Program offices, and ultimately the PMs, are the ones who must navigate through this sea of conflicting requirements to arrive at a solution that sufficiently meets both interests. On the one hand, CrVI has been widely used across the military for decades to alloy metals, treat metal surfaces, and as a constituent in primers for coating systems. There presently exist no other materials with the protective capabilities of CrVI. Unfortunately, CrVI is also a known carcinogen. As its toxicity and environmental impact have become better understood, stricter Environmental, Safety, and Occupational Health (ESOH) regulations have been enacted. The stricter regulations place pressure on industry to eliminate CrVI altogether, avoiding costly procedures, training, and safety liabilities. However, without mature alternatives that perform at the level of CrVI, the DoD will continue to need to use CrVI for applications where no alternative is determined to be acceptable. In such cases, the PM must obtain a waiver to use CrVI. Using alternatives to CrVI, while necessary, comes with a high degree of risk. It is incumbent upon program offices to mitigate these risks through diligent testing and evaluation of potential alternatives.

Program Offices must balance Defense needs against ESOH regulations

CrVI or Alternative: The PM must provide a justification for either decision to the acquisition board

Why do We Need to Minimize CrVI?

Hexavalent chromium has been determined to be a significant cancer risk, causing lung cancer from toxic vapors in manufacturing and maintenance sectors. Skin lesions can occur when contacting chromium powders in industrial applications, and it also poses a significant inhalation risk. It is an environmental hazard which has been determined to cause cancer and birth defects when potable water systems are contaminated. Table 1 provides a comparison of the cancer risk of CrVI to other known carcinogens. As such, stricter regulations have been implemented by OSHA in 2006 regarding the permissible exposure limit (PEL), as listed in Table 2.

The DoD still needs CrVI for applications with no acceptable alternative

Table 1. **Cancer Risk of CrVI in Comparison to Other Known Carcinogens.**[2]

Material	Cancer Risk (per 1000)	Rulemaking Date
Asbestos	6.7	June 1986
Benzene	10	September 1987
Formaldehyde	0.0056 – 2.64	December 1987
Cadmium	3 – 15	September 1992
1,3 – Butadiene	1.3 – 8.1	November 1996
Methylene Chloride	3.6	January 1997
CrVI	10 – 45	February 2006

Table 2. **CrVI Occupational Exposure Limits.**[2]

Country	Occupational Exposure Limit (µg/m³)
United States	
• New OSHA (2006)	5
• Previous OSHA	52
European Union, France, Germany, UK, Finland, China, India, Japan	50
Sweden	20
Denmark	5

Exposure to CrVI is a risk in processing and manufacturing new materials, as well as maintaining systems. Protective clothing and high-volume air ventilation systems are regularly employed to contain human exposure in work settings where CrVI is present. Once incorporated into the base material of a CPC product, such as a primer or a coating, CrVI poses minimal exposure risk, as it is non-friable. It is when CrVI is made friable via a removal operation that the free particles of CrVI pose a serious inhalation risk. The two greatest opportunities for exposure are at the depot level: depainting operations (primarily for aircraft), and welding of stainless steels (shipbuilding). Both these operations can produce

Table 3. **CrVI Functions and Applications.**

Product	CrVI Application/ Process	Purpose	Application	Substrate	Specifications
Anodizing	Chromic Acid Bath	Wear and corrosion resistance, paint adhesion	Aircraft	Aluminum	MIL-A-8625F, Type I, Type IB
Hard Chrome Plating	Electro-deposition	Wear protection, repair/rebuild worn components	Aircraft, vehicles, gun barrels, hydraulic actuators, landing gear		MIL-STD-1501, MIL-C-20218
Chromate Sealant	Incorporated into sealant composition	Water barrier, corrosion inhibitor	Electronics, vehicle panels, fuel tanks, radomes, fasteners, tactical shelters		MIL-PRF-81733, MIL-S-8802
Chromate Primer	Incorporated into primer	Corrosion protection	Aircraft skins, Al airframes, Steel airframes	Aluminum, steel	MIL-F-7179, MIL-P-53022, MIL-PRF-23377, MIL-PRF-85582
Chromate Conversion Coating	Pretreatment bath, wipe, spray	Self-healing coating, sealant for electro-plated and anodized coatings, adhesion surface for paints and sealants	Aircraft skins, Al structures, Mg gearboxes, fasteners, electrical connectors	Al, Mg	MIL-DTL-81706, MIL-C-5541, MIL-M-45202, MIL-A-8625, MIL-C-3171, MIL-C-17711, MIL-M-45202

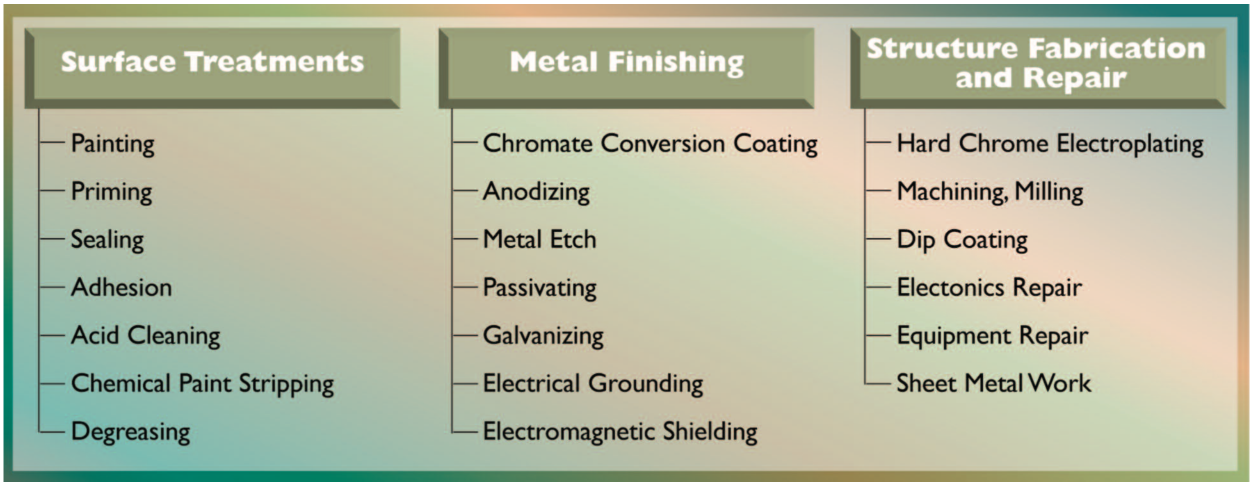

Figure 1. CrVI Use in the Military[3]

high levels of toxic vapors. Disposal of consumable processing materials (such as abrasive media, which becomes contaminated) are also problematic and costly.

The Military Has A Long and Successful History with CrVI

CrVI has been widely used for over 50 years in the military for a variety of functions and on numerous weapon systems and infrastructure, see Table 3. CrVI is used as an alloying component in metals, most notably stainless steels, and for surface preparation and coating systems, as listed in Figure 1. Alternatives to CrVI have been developed for surface treatments and coating systems, with research and development (R&D) still progressing on additional alternatives.

The DoD and Industry Don't View CrVI in the Same Way

There is a fundamental disparity between how the DoD and industry each view and approach the CrVI issue, which are responses largely commensurate with their respective missions. Defending US National interests and protecting its citizens are the primary objectives of the Military Services. The DoD understands the need to manage and control properly the use of toxic materials within that mission. Conversely, the main objective of most private companies is to make a profit, and thus yield a return to their shareholders. As part of their calculus, industry must balance the prospective benefits of market gains against the potential financial risks from liability issues and increased costs of regulatory compliance when using toxic chemicals. In most cases, risk-averse manufacturers are naturally inclined toward eliminating CrVI altogether from their product lines, as they don't see a sufficient return for the risks incurred. Despite such misgivings in the private sector, the DoD cannot let such aversions jeopardize the military's ability to perform its mission in a safe manner. Until alternatives are developed that can perform as well, or better than CrVI for all functional areas, the DoD must ensure that domestic industrial facilities and processes maintain their capability to work with CrVI.

The Military has used CrVI successfully for over 50 years

Using Alternatives May Increase Program Risk

At present, the regulatory impetus to minimize CrVI use is very strong. New acquisition programs will undoubtedly be scrutinized heavily by principals representing ESOH interests to ensure that PMs are making maximal use of alternative compounds in their corrosion planning. It will be critical for program offices to perform due diligence when considering alternative materials, as most available compounds are largely unproven in the field, with very little or no reliable service data to guide material selection choices. Thus, most decisions to use alternatives carry with them inherent risks. These risks manifest themselves as impacts to program objectives: mission success, availability, system performance, safety, schedule, and cost.

The pressure to use alternatives may be considerable

A Cautionary Note: By choosing alternative material schemes over traditional CrVI-based products, program offices may be setting themselves up for several unintended consequences, as chromium is truly multifunctional, providing not only corrosion protection, but many other benefits as well. Chromium makes many metal alloys more resistant to fatigue, enhances wear and abrasion properties, and fosters good adhesion of primers and topcoats to surfaces. CrVI and most chromium compounds are also excellent biocides, thwarting all types of biofouling, such as mold and fungus. Most alternatives were developed specifically with only corrosion resistance or adhesion properties in mind. Thus, program offices may need to incorporate additional materials or additives with selected alternatives to meet specific performance requirements unrelated to corrosion resistance. To reduce program risk, program offices must implement a regimented testing and evaluation strategy to assess quantitatively the suitability of alternative candidates, with evaluation criteria tailored for each specific application.

Most alternative compounds are unproven in the field

There may be other unintended impacts from eliminating CrVI. Alternatives may not protect against fungus, fatigue, wear, or peeling

Even though some alternatives have been qualified/approved for general use, they still need to be tested for each specific application unless the alternative has already gone through a thorough test and evaluation for that case. An example: some alternative conversion coatings have been approved, but only in conjunction with a CrVI-based primer for use on exterior aircraft Al alloys. When an established alternative is being considered for a different application, the alternative coating system needs to be evaluated to meet the new application requirements. For example, using an alternative coating system on an interior may require mold resistance, or similarly, using the alternative on an application where stress loads vary will require mechanical testing of the component to provide reliable data for design allowables. Subject matter experts (SMEs) should be employed to establish the testing and evaluation criteria for components/systems. Lastly, the use of alternatives will likely require new procedures resulting in training of personnel and updating technical manuals (TMs) and technical orders (TOs).

POLICIES AND REGULATIONS

It will be increasingly difficult in the future for program offices to include CrVI-containing compounds as part of their overall corrosion prevention strategy. This is due in large part to the numerous changes in ESOH regulations implemented over the past decade. Recent DoD policies have added to this stricture, by first requiring the Services to more aggressively implement corrosion prevention and control measures in Defense systems and infrastructure, and then subsequently directing Components to minimize, to the degree possible, the use of CrVI in military assets. These new policies push for using alternatives to CrVI as the new default, and only using CrVI in cases where no alternative is acceptable. This section summarizes relevant policies and regulations.

It will be increasingly difficult for Program Offices to use CrVI

The 2003 Wynne Memorandum

Congress passed a provision as part of the 2003 Defense Authorization Act, 10 USC Sec. 2228, which mandated that the DoD institute formal steps to minimize the impact of corrosion to DoD systems and infrastructure. On November 12, 2003, then-Principal Deputy Undersecretary of Defense for Acquisition, Technology, and Logistics (PDUSD/AT&L) Michael W. Wynne issued a memorandum to the Secretaries of the Military Departments directing that corrosion prevention and control planning be an integral part of the initial design and acquisition process, subject to the Defense Acquisition Board (DAB) review. This memorandum set the stage for reduced life cycle costs of new systems by designing-in corrosion resistance.

The DoD is required by law to take effective steps to minimize the impact of corrosion on Defense assets.

The 2009 Young Memorandum

On April 8, 2009, John J. Young Jr., then-Director, Defense Research and Engineering (DDR&E), issued a memorandum to the Secretaries of the Military Departments calling for minimizing the use of CrVI. It was in response to stricter regulations set forth in both the US and Europe. The memorandum does not ban the use of CrVI, rather provides for specific instances where its continued use is acceptable. What it did change specifically was that for all design decisions where CrVI use would be considered, PMs would be required to furnish a rationale and justification for their material selection regardless of whether CrVI or an alternative was chosen. The following actions were called out in the memorandum:

PMs will be required to furnish a rationale and justification for CrVI or an alternative, regardless of choice.

Invest in appropriate research and development on substitutes.

- Ensure testing and qualification procedures are funded and conducted to qualify technically and economically suitable substitute materials and processes.
- Approve the use of alternatives where they can perform adequately for the intended application and environment. Where CrVI is produced as a by-product for use or manufacture of other acceptable chromium oxides, explore methods to minimize CrVI production.
- Update all relevant technical documents and specifications to authorize use of the qualified alternatives and, therefore, minimize the use of materials containing CrVI.
- Document the system-specific CrVI risks and efforts to qualify less toxic alternatives in the programmatic ESOH evaluation for the system. Analysis should include any cost/schedule risks and life cycle cost comparisons among alternatives. Life cycle comparisons should address material handling and disposal costs and system overhaul cycle times/costs due to any differ-

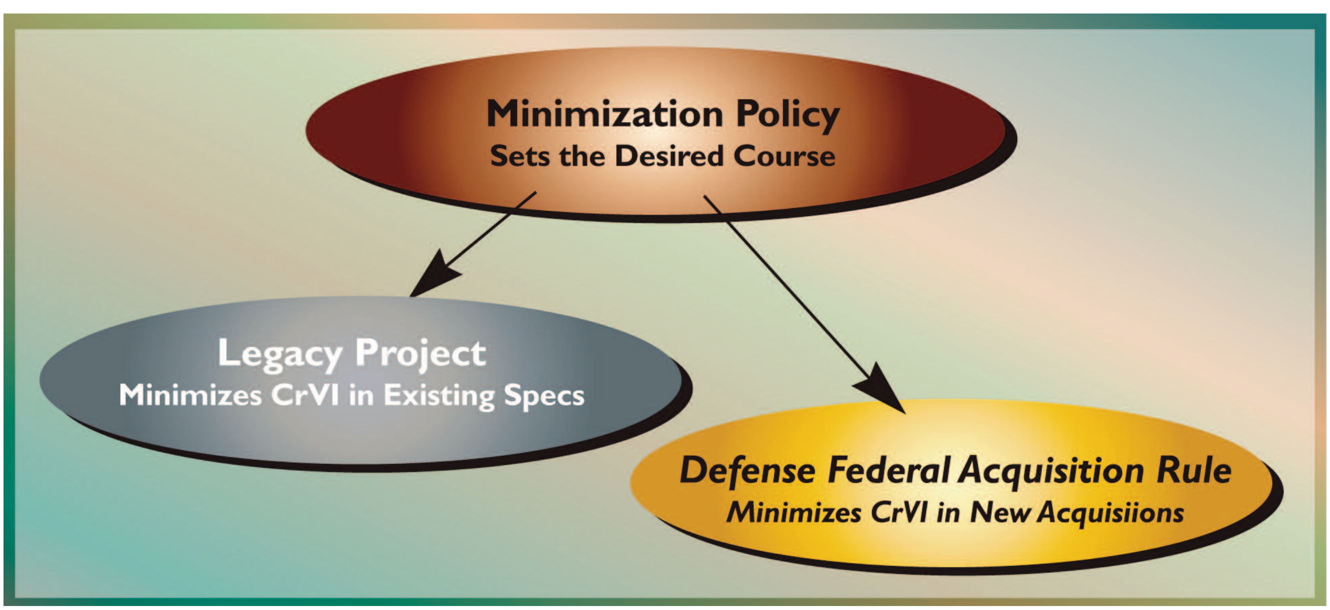

Figure 2. Minimization Policy[4]

ences in corrosion protection.

- Share knowledge derived from research, development, testing, and evaluations (RDT&E) and actual experiences with qualified alternatives.
- Require Program Executive Office (PEO) or equivalent level, in coordination with Military Department's Corrosion Control and Prevention Executive (CCPE), to certify there is no acceptable alternative to the use of CrVI on a new system. This requirement also applies to the operation and maintenance of a system during the Operations and Support phase of a system's life cycle. PEO or equivalent, in coordination with the military department's CCPE, shall evaluate each certification for validity, taking into account at a minimum the following:
  - Cost effectiveness of alternative materials or processes.
  - Technical feasibility of alternative materials or processes.
  - ESOH risks associated with the use of CrVI or substitute materials in each specific application.
  - Achieving a Manufacturing Readiness Level (MRL) of at least 8 for any qualified alternative.
  - Materiel availability of CrVI and the proposed alternatives over the projected life span of the system.
  - Corrosion performance difference between CrVI balance and alternative materials or processes as determined by agency corrosion SMEs.
  - For such applications where acceptable alternatives to CrVI do not exist, CrVI may be used.
- This minimization policy was meant to be across the board, setting a course of action for both new and legacy systems, as depicted in Figure 2.

CrVI and the DFARS

On April 8, 2010, the DoD published a proposed rule on CrVI in the Federal Register at 75 FR 18041. A supplement to this Defense Federal Acquisition Regulation Supplement (DFARS) was enacted on May 5, 2011 for "Minimizing the Use of Materials Containing Hexavalent Chromium." The final rule, in the new supplement, prohibits the delivery of items containing more than 0.1 % by weight CrVI in any homogenous material under DoD contracts unless there is no acceptable alternative.

The DFARS already regulates usage of CrVI in Defense Acquisition

CrVI Restrictions in ESOH Regulations

Numerous regulatory bodies in the US and abroad have imposed restrictions on one or more aspects of CrVI. This subsection summarizes some notable regulations.

Occupational Safety and Health Administration

On February 28, 2006, the Occupational Safety and Health Administration established a permissible exposure limit (PEL) of 5 μg/m^3, measured as an eight hour time weighted average.[5] The regulation affects all industry operations that could generate CrVI air emissions, and applies to all forms of CrVI. The new OSHA rule places the following requirements on employers:

- Monitor employee exposure to CrVI
- Establish separate regulated areas when CrVI levels are expected to exceed the PEL
- Provide respirators for workers exposed above the PEL
- Provide other PPE (personal protective equipment) as necessary for eye and skin protection, together with change rooms and wash facilities
- Institute housekeeping activities to control spills and releases of CrVI
- Provide medical surveillance for employees who are exposed above the PEL, show signs or symptoms of CrVI exposure, or are exposed in an emergency
- Train workers about CrVI hazards, and use signs and labels to communicate the hazards
- Keep records of exposure, surveillance and training.

The PEL action level is 50 % or 2.5 μg/m^3 which requires monitoring. If CrVI concentrations are $<$ 0.5 μg/m^3 under all conditions, then the OSHA rule does not apply.

Environmental Protection Agency

The Environmental Protection Agency (EPA) has instituted both a Clean Air Act and a Clean Water Act.[6] Under the Clean Air Act, air emission limits for hard chrome plating facilities are:

- 0.015 mg m^{-3} (15 μg m^{-3}) of dry standard exhaust air from all tanks in a "large" facility or newer (installed after 1993) "small" facility
- 0.03 mg m^{-3} (30 μg m^{-3}) of dry standard exhaust air from all tanks in an older small facility.

And air emission limits for decorative chrome plating is:

- 0.01 mg m^{-3} (10 μg m^{-3}) of dry standard exhaust air, but control of the bath surface tension is all that is necessary when a fume suppressant with a wetting agent is used

Under the Clean Water Act, hard chrome platers must follow:

- CrVI-contaminated wastewater such as rinse water is properly treated before discharge to the sewer
- The plating plant is constructed to prevent spills that could cause groundwater contamination (which has happened beneath many older chrome plating plants)
- The plating solution or sludge and any CrVI-contaminated materials such as masking materials, air filters, and solids and liquids from air-handling systems are recycled or properly disposed of.

California Regulations

The Airborne Toxic Control Measure (ATCM), enacted by the California Air Resources Board (CARB) applies to all chrome plating and anodizing facilities established prior to 1998.[7] It is similar to EPA's concentration based rule, but is dependent upon ampere-hours used in plating and anodizing processes, and recognizes small, medium, and large facilities. An amended rule was initiated in 1998 to match the EPA, and applies to facilities established post-1998, divided into two categories – small/medium and large facilities.

The ATCM implemented a thermal spray regulation on September 30, 2005, limiting CrVI and nickel emissions. Elements of the regulation include:

- All CrVI and nickel emissions from thermal spray operations must pass through an appropriate control device, which can range from a water curtain to a high-efficiency filter, the type of device being determined by the calculated annual emissions from that operation.
- In the case of nickel, maximum hourly emissions from all thermal spraying operations must not exceed 0.01 lb from an individual source (such as a stack) or 0.1 lb from the whole facility.

Analysis of Alternatives to Hexavalent Chromium

This Guide is a compendium of information resources; providing an extensive summary of the policy, programmatic, technical, safety, and regulatory issues pertaining to the restricted use of Hexavalent Chrome (CrVI). The Guidebook contains six sections organized as such:

Section 1 – Executive Summary
A broad overview of the challenges and strategies associated with the use, or omission, of CrVI.

Section 2 – Background
This section offers a synopsis on the Environmental, Safety, and Occupational Health (ESOH) problems surrounding CrVI; where and how CrVI is used in the military; the differences between how industry and DoD each perceive CrVI; and the impact that using alternatives to CrVI may have on military systems during their service lives.

Section 3 – Policies and Regulations
A summary of policies, regulations, and DoD memoranda regarding the use of CrVI.

Section 4 – Program Management
Written with the program manager in mind, this section addresses the myriad issues that PMs will need to address when considering potential applications of CrVI. It discusses the procedures for evaluating/validating CrVI alternatives; obtaining a waiver to use CrVI in the case that no available alternative is suitable; and lastly, identifies resources available to PMs.

Section 5 – Alternative Selection Flow Chart Process
Designed to serve as an engineering reference for technical personnel, the flowchart and accompanying text outline and describe the recommended material selection process to evaluate and assess the suitability of alternative materials into systems. As part of the process, it also specifies when using CrVI would be the best option, typically when there is no acceptable alternative.

Section 6 – Analysis of Alternatives
Summary information and compiled data collected relative to the performance of alternatives compared to traditional CrVI material systems.

For program managers and many other readers, the entirety of the body of information in this guide far exceeds any one individual's immediate data needs. For readers to get the most information in their respective areas of interest (while bypassing those areas which lie outside), we offer the following recommendations.

Program Managers:	Sections 1, 3, and 4. Section 2 optional
Policy Makers:	Sections 1 and 3
Senior Technical Personnel:	Sections 1 through 5
Engineering Staff & Contractors:	Sections 2 through 6

To obtain a copy, please visit http://ammtiac.alionscience.com/crvihandbook

Table 4. **Military Specifications Involving CrVI and Alternatives.**

Specification	Title	QPL
MIL-A-8625	Anodic Coatings For Aluminum and Aluminum Alloys	-
MIL-DTL 81706B	Chemical Conversion Materials for Coating Aluminum and Aluminum Alloys	Table 11
MIL-PRF-81733D	Sealing and Coating Compound, Corrosion Inhibitive	Table 23
MIL-PRF-85582D	Primer Coatings: Epoxy, Waterborne	Table 26
MIL-PRF 23377J	Primer Coatings: Epoxy, High-Solids	Table 27
MIL-DTL-53022D	Primer, Epoxy Coating, Corrosion Inhibiting Lead and Chromate Free	Table 28
MIL-DTL-53030C	Primer Coating, Epoxy, Water Based, Lead and Chromate Free	Table 29
MIL-DTL-53084	Primer, Cathodic Electrodeposition, Chemical Agent Resistant	-

- A facility is exempt from the requirements when annual emissions of CrVI and nickel are less than 0.001 lb and 0.3 lb, respectively, from an individual source; and less than 0.004 lb and 2.1 lb, respectively, from the whole facility.
- Requirements on permitting, monitoring, record keeping and reporting must be met.

California has also implemented regulations on waste similar to those enacted in Europe. As of January 1, 2003, CrVI has been banned from all motor vehicle and equipment waste, to include off-road vehicles, trains, agriculture equipment, concrete mixers, and wheelchairs. On January 1, 2005, a fee was imposed on covered electronic devices, with the collected funds from fee assessments to be used for proper waste disposal.

European Regulations

European regulations have focused on waste streams rather than air emissions. The End-of-Life Vehicles (ELV) and the Restriction of Hazardous Substances (RoHS) directives serve to eliminate hazardous materials, including CrVI, from waste streams in the vehicles and electrical/electronic industries. The ELV imposes that components of specified vehicles do not contain hexavalent chromium, along with lead, mercury, and cadmium, other than in specified cases.[8] The RoHS bans the use of chromium, lead, mercury, cadmium, poly-brominated biphenyls (PBB), and poly-brominated diphenyl ethers (PBDE) in electrical and electronic equipment exceeding maximum concentration levels.[9]

The Waste Electrical and Electronic Equipment (WEEE) provides for the proper collection of hazardous wastes from electrical and electronic equipment, along with replacement of those hazardous materials including CrVI.[10] The Regulation, Evaluation, Authorization and Restriction of Chemical substances (REACH) requires industry to register information on chemicals in a central database run by the European Chemicals Agency (ECHA), for evaluation of suspicious substances and open to consumers and professionals. The regulation also calls for replacements of hazardous materials, like CrVI.

Canadian Regulations

The Environment Canada (EC) issues regulations under the Canadian Environmental Protection Act.[11] On June 4, 2009, the EC implemented the Chromium Electroplating, Chromium Anodizing and Reverse Etching Regulations, which calls specific methods of CrVI containment, dependent upon the process, for facilities where 50 kg or more of chromium trioxide (CrO_3) is used per calendar year.[12] The Canadian Centre for Occupational Health and Safety (CCOHS) serves to disseminate information on health and safety in the workplace with no regulatory powers.

Military Specifications and Qualified Product Lists

There are Military Specifications that cover CrVI and non-CrVI products together, as well as new specifications developed entirely for non-CrVI materials. Table 4 lists Military Standards and Specifications of interest. Section 6 of the guide contains more information on the relevant military specifications and standards as well as tables of Qualified Products Lists (QPLs) for the specifications. The Military Specifications and QPLs will change over time and may be accessed at: https://assist.daps.dla.mil/quicksearch/

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Professionals Plug Away in Effort to Keep IEEE 45 Current

Electrical Engineers Charged with Changing Electric Ship Standards Need a Power Surge

Edward Lundquist
MCR, LLC

With the growing use of integrated propulsion systems, smart grids, and power electronics on ships, the venerable standard for electrical installations on ships – IEEE-Std-45 – is being updated. New supporting standards are being developed to support both military and commercial ship designs.

This task is a large one, and the chair of the IEEE-45 Standard Coordinating Committee, Moni Islam, says both new ideas and more volunteers are needed to complete the mission. "In the process of standards development, we are initiating fundamentals of design changing how we will design electrical systems in ships in the future," says Islam. Islam says he has an all-star team of experts to take on this very large task, but more qualified engineers are needed. "We want to encourage people to help with this effort," Islam says.

Islam says that those who come forward to work with the standard development team will join experts from the Navy, Coast Guard, American Bureau of Shipping (ABS), academia, and industry. And, he says, they will be making a real contribution to the profession. "All the team members have a say in the proposed standard," Islam says.

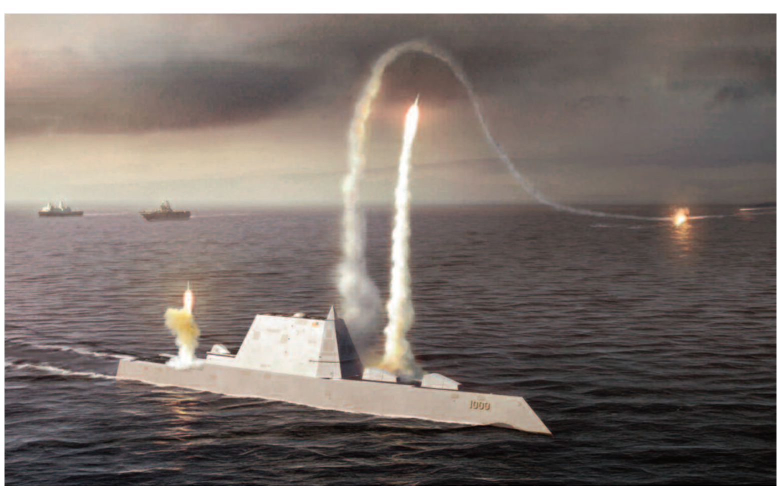
Last revised in 2002, the longstanding standard needs to be updated to allow for new methods of integrated power systems and power electronics. Integrated Power Systems being installed aboard the new ships such as Navy's new DDG 1000 and the Royal Navy's Type 45 destroyers feature installed power that is available for propulsion, sensors, weapons, and ship service. So sophisticated power management systems are needed to manage those loads. If part of the system is knocked out, "graceful degradation" of the systems will ensure the most vital loads remain on line. Graceful degradation offers reliability, and the use of mature and ruggedized commercial-off-the-shelf (COTS) based technologies will result in total ownership cost savings.

"We want to give this information in simple terms so that everybody interested in fundamental ship design can contribute to supporting those changes," Islam says.

"We are involved in a new, emerging and rapidly changing technology. We are bringing an old technology – electric power – into a new world environment," says Paul Bishop of the Bishop Group, who chairs the P45.3 Systems Integration and P45.4 Mission Systems standards teams as well as the IEEE Power and Energy Society's Marine Systems Coordinating Committee. "We are making things practical today that were not even considered possible just 10 years ago."

A large number of standards are currently under development, Bishop says. "These standards are establishing the rules for the electric transfusion."

"IEEE 45 is the foundation for guiding an engineer in the design of a shipboard power system," says Dr. Norbert Doerry, a technical director at the Naval Sea Systems Command. "Power systems onboard ships have evolved considerably over the recent



An artist's rendering of the Zumwalt-class destroyer DDG 1000, a new class of multi-mission US Navy surface combatant ship designed to operate as part of a joint maritime fleet, assisting Marine strike forces ashore as well as performing littoral, air and sub-surface warfare. (Photo courtesy of US Navy)

past with the increased use of integrated power systems, power electronics, and advanced control systems. The traditional 60 Hz. AC450 volt 3 phase ungrounded distribution system is no longer the favored option for many ship designs. The ongoing update of IEEE 45 recognizes these changes have happened."

Islam explains the basic change is not complicated. "The traditional 450-volt electrical system found onboard ships today is ungrounded delta for low-voltage systems; and for medium-voltage systems high resistance grounding is the common system. The fundamental difference is that we will be making low and medium voltage the same. Low voltage systems will change to resistance grounding."

The devil is in the details says Joe Piff, an electrical engineer with MCR Federal who serves on the committee. "We can determine that we need a standard plug to connect systems," Piff says. "But then we have to determine what colored wire goes to what pin."

IEEE-45 will remain as the overarching standard for electric ship design, but eight new "dot" standards have been approved. This progressive new standard will permit new electric-ship designs with Integrated Propulsion Systems (IPS). The IEEE-45 standard was first released in 1920. To support the new IPS designs, the current update is looking at many issues that come under the standard, such as design, controls, integration, testing and others.

Dennis K. Neitzel, CPE, IEEE Senior Member, director emeritus of the AVO Training Institute in Dallas, says that anyone who has shipboard electrical experience should be involved with the effort. "Input from those who know is vital to the usability of a standard."

Islam is looking to the research community to engage and address the offshore issues, provide data, and express the results in a form for practical applications. He is looking forward to Office of Naval Research (ONR) sponsored Advanced Electrical Power System (AEPS) engineers sharing the challenges they are facing to address protection coordination issues. "We need more work in system protection coordination, and then it needs to be simplified to meet the guidelines expressed through the IEEE standards. This research must be done before it can be addressed at the standard development level," Islam says.

He is also looking to hear from the Variable Frequency Drive (VFD) manufacturers so they can share their issues related to the system-level protection challenges.

"I appreciate the offshore industry personnel coming forward with issues which must be addressed by various communities, such as research entities, equipment manufacturers, and systems of system designers," he says.

Individuals who would like to participate in this important effort to update IEEE-45 may contact:

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Captain Edward Lundquist, US Navy (Ret.) is a principal science writer for MCR Federal, LLC and has more than 27 years of public affairs, public relations, and corporate communications experience in military, private association, and corporate service. During his 24-year naval career, Mr. Lundquist qualified as a Surface Warfare Officer and later served as a Public Affairs Officer. He retired from active duty in 2000. Lundquist currently is member of the executive committee for the Surface Navy Association, and serves as vice president of the Greater Washington Chapter. He is an Accredited Business Communicator (ABC) and the vice chair of the International Association of Business Communicators Accreditation Council. Lundquist is a graduate of Marquette University in Milwaukee, Wisconsin and holds a master's degree in journalism and public affairs from the American University in Washington, DC. He writes frequently for publications including Armed Forces Journal, Unmanned Systems, Naval Forces, Warships International, Maritime Reporter, and others.

New Technical Resource for Scientists and Engineers:

Nondestructive Testing Overview

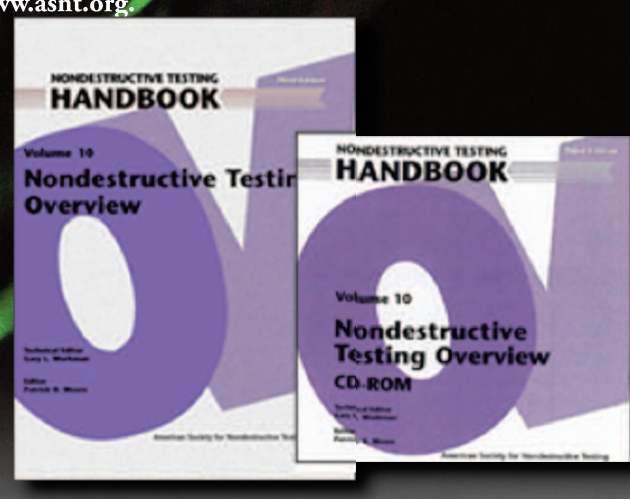
Nondestructive testing is a broad spectrum of analytical techniques based on physical principles, and it utilizes technical aids ranging from the primitive lenses to state-of-the-art imaging. As equipment, machinery, and systems become more sophisticated and dependent on quality components, the field of nondestructive testing becomes increasingly vital. Although nondestructive testing has been applied in one form or another for nearly a century, the field continues to advance rapidly. The American Society for Nondestructive Testing (ASNT) recently published the Third Edition of its handbook that presents an overview of nondestructive testing to capture the latest advancements in the rapidly changing field. As Volume 10 in the *Nondestructive Testing (NDT) Handbook Series*, *Nondestructive Testing Overview* strives to encapsulate the various techniques and technologies that constitute nondestructive testing. It covers each NDT technique in sufficient detail to serve as a useful technical reference for the experienced testing engineer, but also presents the content in a manner that can help educate those not previously involved with nondestructive testing.

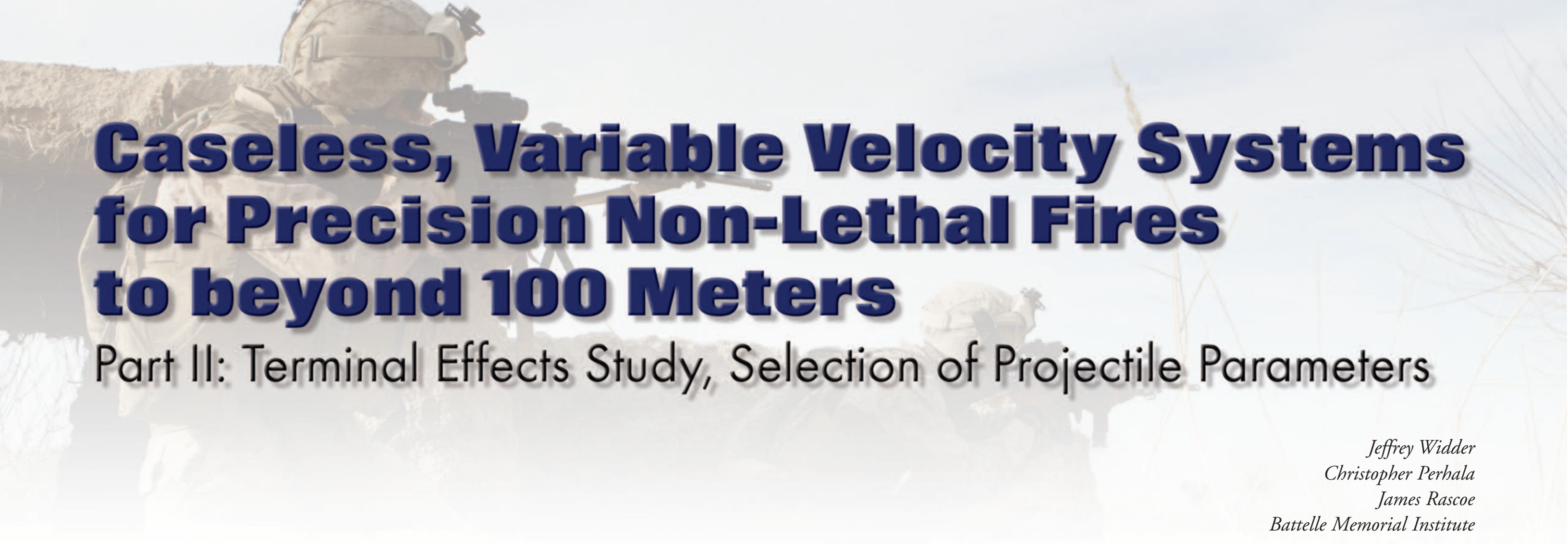
The handbook provides a basic introduction to nondestructive testing and an exhaustive bibliography of historically significant works pertaining to nondestructive testing.

This 594 page reference book on nondestructive testing includes – among several other topics – chapters on Visual Testing, Liquid Penetrant Testing, Leak Testing, Infrared and Thermal Testing, Radiographic Testing, Electromagnetic Testing, Magnetic Particle and Flux Leakage Testing, Ultrasonic Testing, Acoustic Emission Testing, Vibration Analysis, Laser Testing, Alloy Identification, and Strain Measurement. A glossary is included to provide definitions and descriptions of technical terms associated with nondestructive testing.

The development of the *Nondestructive Testing Overview* handbook was a collaborative effort with contributions from experts that are working in this field for academia, industry, and government organizations. The reference therefore gives a comprehensive overview on the proven and potential applications of nondestructive testing techniques. Detailed procedural information as well as equipment and instrumentation calibration methods is included throughout the book.

The *Nondestructive Testing Overview* handbook, which was published in 2012, is currently available from ASNT. The reference can be purchased in CD ROM and/or bound hardcover form from www.asnt.org.





Caseless, Variable Velocity Systems for Precision Non-Lethal Fires to beyond 100 Meters

Part II: Terminal Effects Study, Selection of Projectile Parameters

Jeffrey Widder
Christopher Perhala
James Rascoe
Battelle Memorial Institute

This issue features a follow-up to Dr. Widder's article on variable velocity, non-lethal ballistic weapons, which was published in Volume 1, Number 1 of the AMMTIAC-WSTIAC Journal *(http://ammtiac.alionscience.com/pdf/AWJV1N1.pdf). The original article summarized the approach to designing an improved non-lethal ballistic system and presented results from testing the new system. The follow-up article in this issue presents more detail about the system parameters and design, including some of the variables and challenges that face designers of non-lethal ballistic weapons.* - Editor

INTRODUCTION

This terminal effects study was performed to identify design parameters for the Battelle caseless, non-lethal projectile and identify the range of impact velocity needed for an escalation of force approach. At the low end of the force spectrum, the impact should cause a short duration pain with no debilitating effect. At the upper end of the force spectrum, the level and duration of the pain should have a debilitating effect for several minutes to hours. In choosing appropriate impact characteristics for a non-lethal blunt impact weapon, several things must be considered. First, what is the scenario for use and the desired outcome? For instance, one scenario for use is that a non-violent crowd is gathering, and there is risk that the crowd could grow violent or become agitated due to the presence of instigators. In such a case, the desired outcome may be to prevent escalation and peacefully disperse the crowd; if the bull horn has failed to achieve this task, some level of force is needed.

In general, it is best to use a minimal level of force such as tear gas, flash bang grenades, and maybe soft-hitting kinetic rounds, such as the Battelle projectile fired to have a low impact velocity. The goal of this tactic is to reduce the number of individuals the warfighter must confront by dispersing the "casual observers" and those who do not wish any serious repercussions for themselves. For a non-agitated crowd, this may be all that is required to get them to disperse; however, if some fraction of the crowd still resists, an additional increase in the level of discomfort may be needed to encourage compliant behavior. At this point, it may be desirable to apply a greater level of force to specific individuals that are leading the group. The Battelle non-lethal system has the accuracy and scalability to target individuals with successively harder hitting fires at ranges up to and likely beyond 100 meters.

There are two ranges for the increased level of impact that can be used; the first increased range of impact is a small escalation over tear gas and has a low risk of injury for impacts to the torso, abdomen, and extremities. This can be called the "paintball" level of impact and can be achieved with the Battelle non-lethal system by firing in the reduced velocity mode when the range is less than 60 meters, or at intermediate muzzle velocity when the range is greater than 60 meters. If the person is not wearing heavy clothing or padding, the impact will produce a sharp, short duration pain that will likely deter less motivated individuals. Persons wearing heavy clothing or padding as a countermeasure will likely not be deterred by this level of impact; a higher level of impact is required.

As the level of impact increases, the likelihood of the desired compliant behavior also increases, but so does the risk of producing injuries that can be used by our adversaries to claim excessive force and achieve a political success against us. It is important to understand what the risk of injury is as the impact velocity increases, and take that into consideration as the level of applied force is increased. At an increased level of impact, simple countermeasures such as padding can be defeated, and the weapon can be used to temporarily incapacitate persons to aid in apprehension or disable and repel rock and Molotov cocktail-throwing individuals to ranges where they are ineffective. It is this level of impact that the Battelle non-lethal system is designed to produce when fired in the higher muzzle velocity modes. At these higher levels of impact, the large variation in human tolerance to blunt impact and the risk of penetrating injuries must be considered, particularly for the scenarios in which the appearance of excessive force can be counterproductive to overall mission goals.

VARIABILITY IN HUMAN TOLERANCE – IMPACT ON NON-LETHAL WEAPONS USAGE

The primary performance goal for non-lethal blunt impact weapons is that they transfer a sufficient amount of energy to the target to have the desired effect, whether it is a moderate-to-high level of discomfort or some level of incapacitation that does not cause injuries that are permanent or that require medical treatment beyond simple first aid. Unlike lethal weapons that are designed to exceed these thresholds, non-lethal weapons must have a terminal effect that is between two not very well defined thresholds. The lower threshold is the level of discomfort required to produce a compliant behavior by the target. The upper level is the threshold above which too severe an injury occurs. Ensuring that the terminal effect of the weapon is between these two thresholds is compounded by the variability in human tolerance to blunt impact and pain as well as things as simple as the thickness and weight of clothing worn.

Variability in human tolerance is one of the greatest obstacles to the development and use of effective non-lethal weapons that do not produce injuries of disproportionate severity to the offense and/or intended action. The variability in tolerance to pain and the physiological effect (severity of injury) can be large from person-to-person and varies across different parts of the body on the same person. The large variation in size and health of a population result in large variations in tolerance to blunt trauma. Producing a blunt impact weapon that will have a very low risk of injury across the spectrum of the population will result in a weapon that is likely to be ineffective against most of that population. Predicting the risk of serious injury of a non-lethal projectile by using impact velocity, energy, or momentum as a threshold is not sufficient, because the combination of many parameters influences how the projectile will interact with the body. The terminal effect of a projectile is a function of many parameters that include: terminal velocity, mass, cross-sectional density, shape, and compliance (compressibility) of the projectile; along with the physical condition (health), age, weight, and location of the impact on the person. Therefore, when predicting risk of injury, one needs to consider the properties of the projectile as well as the impacted person.

Non-lethal human effects models are developed from dose-response relationships generated by experimentation and from the refinement of existing models for nonlethal weapon application.[1]

When deploying non-lethal weapons, the risk of injury (injury beyond what is acceptable for the offense) with each weapon will vary with the region of the body impacted, but also more importantly with the size, physical condition, and age of the person impacted. In general, any non-lethal projectile will produce a severe eye injury from impact to the eye (and possible death from fracture/penetration of the orbital bones behind the eye) except for sting balls and very compliant foam projectiles. Fracture of facial bones, and injury to the eye from impacts to the orbital bones is also very likely. Impacts to the throat can also cause severe injury and death. To reduce these types of facial and throat injuries, the head, facial, and throat region should not be targeted.

With the target areas being the thorax, abdomen, and extremities, the largest risk comes from the variation in human tolerance. When designed to be effective against healthy 50th percentile males, severe injuries should not occur, provided the projectiles do not penetrate and impact is to the thorax, abdomen, or extremities. However, small-stature persons, persons suffering from malnutrition and other poor health conditions, the elderly, pregnant women, and children are all at increased risk of severe injury from blunt impact weapons designed for use against healthy 50th percentile males.

The presence of persons of increased risk needs to be considered when non-lethal weapons are being deployed. Severe injury of "casual observers," particularly woman, children, and the elderly, even if they are the provocateur, can have a long-term negative effect on mission goals and be used by our adversaries to their advantage. Of equal importance in estimating the risk when deploying blunt impact weapons is that heavy clothing, particularly the kind worn in cold weather, decreases the blunt impact effect and thereby the effectiveness of the weapon.

VARIABILITY IN HUMAN TOLERANCE – METHODOLOGIES USED TO PREDICT INJURY RISK

In assessing the risks of injury from blunt trauma non-lethal weapons, one must consider what types of injury are possible and then identify methods to estimate and rank the level of risk and severity of that type of injury. For blunt trauma projectile weapons, the most likely types of injury are blunt trauma injury to the throat, thorax, and abdomen; facture of facial bones and bones of the hand and foot; eye injury; brain injury; and penetrating injury (beyond skin tearing and abrasion). To assess these risks, models and test methods have been developed. In general, the blunt injury tests are standardized to predict risk relative to a healthy 50th percentile male, defined as 5 feet, 6 inches (176 cm) tall, weighing 170 pounds (77 kg). If we start with the assumption that the blunt impact non-lethal weapons in use have an acceptable level of risk when used against a healthy 50th percentile male, we can consider how variations in the population and deviation from 50th percentile male affect the intended impact effect and thereby result in either too severe an injury, or insufficient energy to be effective.

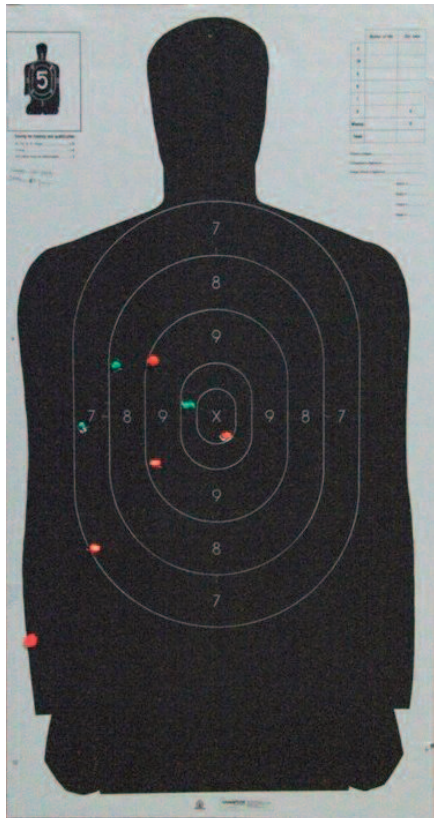
The first criterion for these weapons is that they be non-penetrating. Several models have been developed by the DoD to look at the risk of penetration from flying debris.[2,3] These models predicted either the striking velocity, at which there was a 50% chance of penetration, or the probability for penetration on bare skin and skin covered by two layers of clothing. In general, these equations related cross-sectional area to impacting energy. Penetration was defined as a laceration through the skin. Walter Reed Army Institute of Research established an energy density threshold of 20.6 J/cm^2 that was based on penetration studies of air gun pellets and bullets.[4] The Israeli Military Industries used a threshold of 30 J/cm^2 for their muzzle launched ordnance. More modern work with fresh unembalmed cadavers (from persons of age 58 to 80 years) using a 12-gauge, non-lethal rubber projectile defined penetration as disruption to the underlying tissue (subcutaneous fat and/or muscle). Tearing or laceration of the skin only was not recorded as penetration. Penetration is defined as the point where the resulting injury may require medical treatment. This work resulted in predictions for 50% probability of penetration for impact locations on the front and back of the thorax, abdomen and thigh. The range of energy density for 50% probability of penetration ranged from 23.99 to 52.74 J/cm^2.[5] These studies were performed on fresh cadavers of elderly men and women and likely under-predict the penetration threshold for healthy 50th percentile males. They show that for regions of the body that are the primary target for blunt impact weapons (the thorax, abdomen, and thighs) that there is a factor of two difference in the threshold for 50% chance of penetration. In general, lower energy density was required to penetrate the front of the body. The back was more resistant to penetration due to heavy muscle and thicker skin. The presence of clothing likely reduces the risk of penetration, with the greatest decrease in risk when the clothing is heavy or padded.

Blunt impact testing with hard, flat-nosed cylinders to the thorax and abdomen on surrogates performed in the mid 1970's by the US Army[6] resulted in models for predicting the likelihood of lethality from a thorax impact and the likelihood of liver fracture from an abdominal impact over the liver. The models related the kinetic energy of the impactor normalized to the size of the animal impacted, the diameter of the impactor, and the thickness of tissue at the point of impact, to the level of injury sustained. The model that best predicted the experimental results used five parameters and became known as the Blunt Criterion (BC) where $BC = \ln (E/(TDW^{1/3}))$ in which E is the kinetic energy in Joules of the projectile, T is the thickness in cm of tissue under the point of impact, W is the mass of the impacted person in kg, and D is the diameter of the projectile in cm. The following relationship can be used to estimate T, $T=kW^{1/3}$, where k = 0.711 for males and 0.593 for females. The BC has recently been reanalyzed and shown to have a linear relationship to the Viscous Criterion (VC),[7] when the VC is measured for impacts with similar hard, flat-nosed cylinders on fresh cadavers. The VC is a validated method for predicting severity of blunt trauma from an impact. The VC is an experimentally measured term that relates the maximum in the product of the instantaneous velocity of tissue or chest wall compression with the degree of compression to the level of resulting injury on the abbreviated injury scale (AIS). [8] The relationship between VC and BC has been shown by Bir and Vian to allow estimation of the AIS level of injury[9] from the calculated BC as follows: AIS = 1.33BC + 0.60.

The BC is a term calculated from known projectile parameters (i.e., mass, diameter, velocity) and from target properties (i.e., weight and thickness of tissue) that can be assumed for given scenarios. This allows us to graphically show how changing the size of the person impacted either increases or decreases the risk of blunt trauma injury. It also allows investigation of how changes in mass, diameter, and striking velocity of the projectile may influence the risk of injury, either increasing or decreasing it. Bearing in mind that the relationship of BC to AIS was developed with non-compliant flat-nosed cylinders, it likely overestimates the severity of injury when the impactor is of a compliant design or the impacted person is wearing heavy or padded clothing.

SELECTION OF PROJECTILE PARAMETERS

To be effective against persons using heavy clothing and padding as a countermeasure, and to be effective at temporarily incapacitating a person, the projectile needs to hit hard and produce significant instantaneous pain. To have an acceptably low risk of injury, the impactor should produce a predicted AIS level injury for an impact to the thorax less than 2, the threshold for moderate injury. An AIS Level 1 injury will not require medical treatment, and AIS Level 2 may require medical treatment and certainly will have a longer period for full reversal to pre-engagement level of capability.



Battelle non-lethal ballistic system demonstration at an indoor range. Green ear plugs are off hand shots at 35 and 65 yards, and the orange ear plugs are off-hand, sitting shots taken from 100 yards.

Battelle non-lethal ballistic system demonstration. A 10 shot group was fired outdoors from the prone position at 115 yards (one of the 10 shots hit below the target).

If we assume that a kinetic energy density of 30 J/cm^2 is the maximal permissible, based on risk of penetration beyond tearing of subcutaneous layers of fat and muscle (i.e., full projectile penetration), then we must pick a projectile cross-section that keeps the total kinetic energy of the round below thresholds for other severe injury. Skull fracture from impact with steel drop weights typically occurs over a range of 33 to 75 ft-lbs,[10,11] and fracture of the facial bones has been observed in the automotive crash test studies to occur from 30 to 40 ft-lbs for the mandible and maxilla and 4 to 10 ft-lbs for the zygomatic arch. A kinetic energy threshold below that for fracture of the zygomatic arch would result in an ineffective blunt impact. However, a kinetic energy threshold of 30 ft-lbs, which is below the fracture thresholds of the other bones listed, can result in an effective blunt trauma impact.

This is consistent with the historic, non-lethal animal effects studies of the late 1970's in which the US Army Human Engineering Laboratories and the Swedish Research Institute correlated the kinetic energy of a projectile to injury sustained by impacted surrogate animals. Recommendations to limit kinetic energy for non-lethal projectiles were made based on their experimental results. The Human Engineering Laboratories described projectiles with energies below 30 ft-lbs (40.5 J) as having a low probability of causing an injury. Projectiles with energies between 30 and 90 ft-lbs (40.5 and 121.5 J) were considered dangerous, and projectiles with energies above 90 ft-lbs (141.5 J) were likely to cause "severe damage."[12]

Eye injury also must be considered, but like fracture of the zygomatic arch, it occurs at energies far below what is effective as a blunt impact. Stewart concluded that eye penetration by small spheres occurred at an impact energy density of 6 J/cm^2 plus or minus 1.5 J/cm^2.[13] It is likely any blunt impact weapon will produce severe eye injury. Examples where paintballs impacted the unprotected eye have been recorded in many case studies, and impacts to surrogate pig eyes with paintballs at 300 ft/sec (91 m/sec) have been shown to cause rupture and shattering of the eye globe.[14]

If the kinetic energy of the Battelle projectile is limited to a maximum of 30 ft-lbs (40.5 J) and a kinetic energy density of 30 J/cm^2 at impact, the calculated diameter of the projectile is 1.31 cm (0.516 inch). Without an exemption from the Bureau of Alcohol

Tobacco Firearms and Explosives we are constrained to a projectile of 0.505 to 0.510 that can be fired through a .50 caliber barrel. The projectiles developed for the Battelle non-lethal system have a diameter of 0.506 inch which is 2% smaller than our calculated "ideal." The mass of the presently designed and constructed Battelle projectiles is 8.7 grams. At a striking velocity of 320 ft/sec the projectile has the maximum 30 ft-lbs of impact energy and an energy density of 31 J/cm^2 which is 3% over the maximum identified above.

The kinetic energy of the projectile described above at an impact velocity of 320 ft/sec will have a low risk of causing skull fracture and fracture of the mandible and maxilla and low overall risk of blunt trauma using the kinetic energy threshold mentioned above. Impact to the eyes and orbital bones will result in severe injury. Using the relationship between BC and AIS, given above, a prediction of the AIS level of injury for an impact to the thorax can be made. For the Battelle projectile at the muzzle, the predicted AIS level for a 50th percentile male is 1.8 which compares closely with some of the bean bag rounds, also at the muzzle. The 12 gauge sock rounds impacting at 280 fps has calculated AIS of 1.7 if the sock is assumed to instantaneously open to a 2 inch diameter on impact.

Lastly, we can use the models developed at the Edgewood Arsenal referenced above to look at the risk of liver fracture from impacts to the abdomen over the liver. The Edgewood Arsenal found experimentally that if the value of $MV^2/WD < 414$, where M is the mass of the projectile in kg, V the impact velocity in m/sec, W the mass of the impacted animal in kg, and D the diameter of the projectile in cm, none of the animals impacted exhibited liver fracture upon necropsy. If the value was between 414 and 1,451, then 50% of the animals exhibited liver fracture upon necropsy. When the value was over 1,451, all the animals impacted exhibited liver fracture upon necropsy.[6] The value for the 8.7 gram, Battelle projectile striking with a velocity of 320 ft/sec (97.5 m/sec) is 911, which puts this in the middle of the range where liver fracture occurred in 50% of the impacted animals. This is also comparable to most other non-lethal ballistics which also fall within the 50% range. Since the Edgewood Arsenal did not identify the severity of the liver fracture, severity estimates cannot be predicted from this model. Small liver fractures will heal without treatment, provided there are no other extenuating or aggravating conditions.

All free flying non-lethal ballistic projectiles have the greatest risk of causing a severe injury at the muzzle where the velocity of the projectile is at a maximum. If the .50 caliber projectile is fired with a muzzle velocity of 320 ft/sec (97.5 m/sec), it will never exceed thresholds identified above. It will still be an effective blunt trauma deterrent at a range of 70 meters where the impact energy will have dropped to 68% of the 97 m/sec energy. If it is desirable to have a lower risk of injury, the Battelle non-lethal system can be fired in a lower velocity mode or the system can be designed to fire larger diameter projectiles so that impact energy density and momentum density are lower for the same impact energy.

By the use of tactics, techniques, and training, the risk of severe injury can be decreased by targeting the heavy muscle groups of the lower extremities when circumstance permits or by firing at reduced muzzle velocity. Further, by not targeting persons who are at increased risk, specifically children, pregnant women, small-stature adults, the elderly and the malnourished, the risk of severe injury is further reduced.

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Dr. Jeffrey Widder received his doctorate degree in chemistry from Duke University in 1993 for his research on model lithium electrodes. As a graduate student he developed a passion for metal working and machinery and produced much of the laboratory equipment used in his research. Upon completion of his degree, Dr. Widder accepted a research fellowship through the National Research Council to do photo-acoustic spectroscopy of propellants undergoing pyrolysis at the Army Research Laboratory (ARL), Aberdeen Proving Ground. While at ARL, Dr. Widder became involved in non-lethal ballistics development and testing. In 1997 Dr. Widder accepted employment with Battelle Memorial Institute and was assigned to their Bel Air, Maryland, office. Troubled by previous problems with the performance of non-lethal ballistics, Dr. Widder conceived of a self-propelling projectile and built a prototype. Battelle provided Independent Research and Development (IR&D) funding to pursue a demonstrable launcher and ammunition. Dr. Widder refined the design of the projectile, set up a testing range, and a manufacturing capability to produce and assemble the projectile components and launchers used to test and demonstrate the systems.

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