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Developments in Bomb Suit Testing and Standardization

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Introduction

Historically, bomb suit manufacturers did not have a standard for protection, capabilities, and mobility. Consequently, they had to borrow standards from adjacent industries, such as standards for motorcycle helmets or small arms ballistic protection, then find a way to apply those to the unique context of protecting against an explosive blast. As a result, test methods were inconsistently adapted between laboratories and many results could not be reproduced or trusted. On occasion, bomb suit suppliers made unsubstantiated claims of their product's performance or provided questionable test data from laboratories which may not have adhered strictly to approved test methods. In addition, most end-users or procurement agencies were not sufficiently qualified technically to evaluate the diverse test reports for suitability, adequacy, or accuracy.

The release of the United States National Institute of Justice NIJ 0117.01 standard for Public Safety Bomb Suits [1], in 2016, addressed the gap in standardized EOD Personal Protective Equipment (PPE) evaluation. This standard is intended to provide objective evidence and confidence in performance of EOD suits once they are officially certified by the accredited authority. The NIJ bomb suit standard outlines in detail a significant list of baseline performance and capability to be expected in a bomb suit along with associated testing methods and pass/fail criteria. To maintain independence and credibility, NIJ testing and certification can only be achieved through an officially accredited third party, NIJ-approved, certification organization. This organization overvsees the entire certification process, including initial and annual testing, as well as audits of the manufacturing facilities where the suits and helmets are built. In addition, the certification organization is responsible for announcing and posting which bomb suit models are currently certified. This extensive and exhaustive independent evaluation and oversight instills confidence in performance claims for certified bomb suits.

However, while a critical step forward for the EOD community, the NIJ 0117.01 remains a "minimum standard", given that its requirements do not address all the possible protection and functional requirements bomb technicians may require. In addition to selecting a certified suit, end-users must also consider additional features, which may not be currently outlined within NIJ 0117.01. For instance, the current NIJ standard does not include quantitative requirements for blast overpressure mitigation, CBRN compatibility, personal cooling performance, communications, electromagnetic compliance, minimum power requirements, remote controls, lighting, etc. Furthermore, threats will evolve as will technology available to provide protection against such threats to EOD personnel, requiring a periodic update/upgrade of the standard.

This paper first emphasizes how the NIJ standard can help government agencies in the selection and procurement of EOD PPE, without needing wide ranging technical expertise to assess, evaluate and qualify a bomb suit from all engineering disciplines. These areas of expert evaluation include protection against all blast threats, human factors, optics, field of view, electronics, manufacturing quality, labelling, etc. This paper also emphasizes the need to consider other important features beyond NIJ certification, to ensure that end-users' needs are met.

The NIJ 0117.01 standard for Public Safety Bomb Suits

In 2016, the US National Institute of Justice released the NIJ 0117.01 standard, covering a wide range of requirements of direct relevance to EOD threats and operations, such as:

- V50 Fragmentation protection (inspired from MIL-STD-662 [2]): Pass/fail requirements are based on three different fragment simulating projectiles (17, 44, 207-grain, Figure 1). The large 207-grain (13.4 grams) fragment permits reliable V50 rating determinations for areas of the suit that offer the greatest protection, such as the chest plate. This eliminates the need for questionable V0 ratings, which can not be obtained based on STANAG 2920 [3].

V0 ratings are impossible to obtain because no known laboratory can consistently launch projectiles at 1.5 times the estimated V0 velocity to obtain proper V0 values for high protection armor levels of the chest and groin of bomb suits.

- Spine Protection: The NIJ standard includes a spine protector test methodology developed specifically for bomb suits with appropriate pass/fail thresholds. This addresses the critical need for blunt impact protection when a technician is propelled by the force of a blast, as highlighted through analysis and protection tests [4].
- Head Impact Protection: The NIJ standard includes a very extensive helmet impact attenuation test series (72 drop tower impacts on 9 different helmets, Figure 2). The impact energies and pass/fail thresholds are customized for EOD operations, recognizing the importance of head impact protection to mitigate the risk of traumatic brain injury, as highlighted through analysis and protection tests [5]. The impact tests are conducted at three temperatures (-10°C, +20°C and +55°C), to simulate harsh climates. Each helmet must be impacted in at least four different locations, such as the front, rear, left and right sides.
- Flame Resistance: The standard includes flame resistance tests for the suit outer shell materials and the helmet shell, based on ASTM D6413-99. The pass/fail requirements are customized for EOD applications, ensuring protection against the fire threat from IEDs.
- Blast Overpressure: The standard includes the qualitative evaluation of bomb suits against a 0.567 kg C4 charge at a standoff of 0.6 m, with a Hybrid III mannequin in a kneeling position (Figure 3). Many qualitative requirements are included (protection to remain in place, no underlying mannequin parts exposed after a blast, etc.) As the NIJ standard does not currently address quantitative blast overpressure protection requirements, the ASTM Working Group WG22759 is presently defining a standardized test method for bomb suit quantitative overpressure evaluation, complementing the NIJ suit blast integrity test. An overview of some progress made towards the development of a test methodology for blast overpressure evaluation of bomb suit can be found in two publications [6, 7].

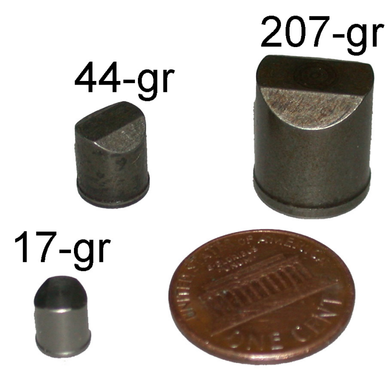

Figure 1: NIJ 0117.01 Fragment Simulating Projectiles (17, 44 and 207-grain). The large 207-grain one eliminates the need for V0 tests.

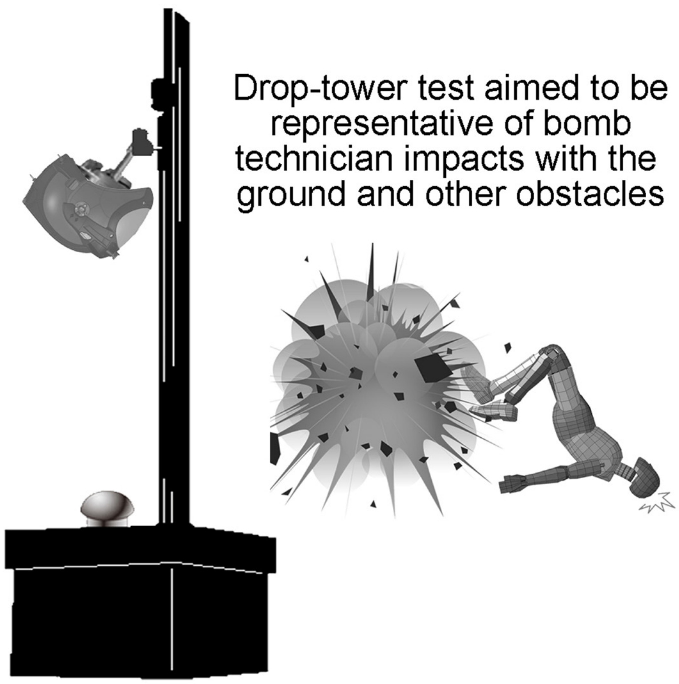

Figure 2: Helmet drop tower testing relevant to traumatic brain injury. 72 drops conducted at 3 temperatures.

- Static and Dynamic Field of View (FOV): While the bomb suits' primary objective is to protect from the main blast threats, EOD ensemble designs must also optimize the flexibility and mobility required for bomb disposal operations. As such, the NIJ standard includes stringent field of view requirements. The static field of view test (Figure 4) is conducted with a headform and a laser system, ensuring objective measurements with thresholds determined based on actual bomb technician requirements (e.g. downward field of view when manipulating devices, horizontal field of view for peripheral vision). The

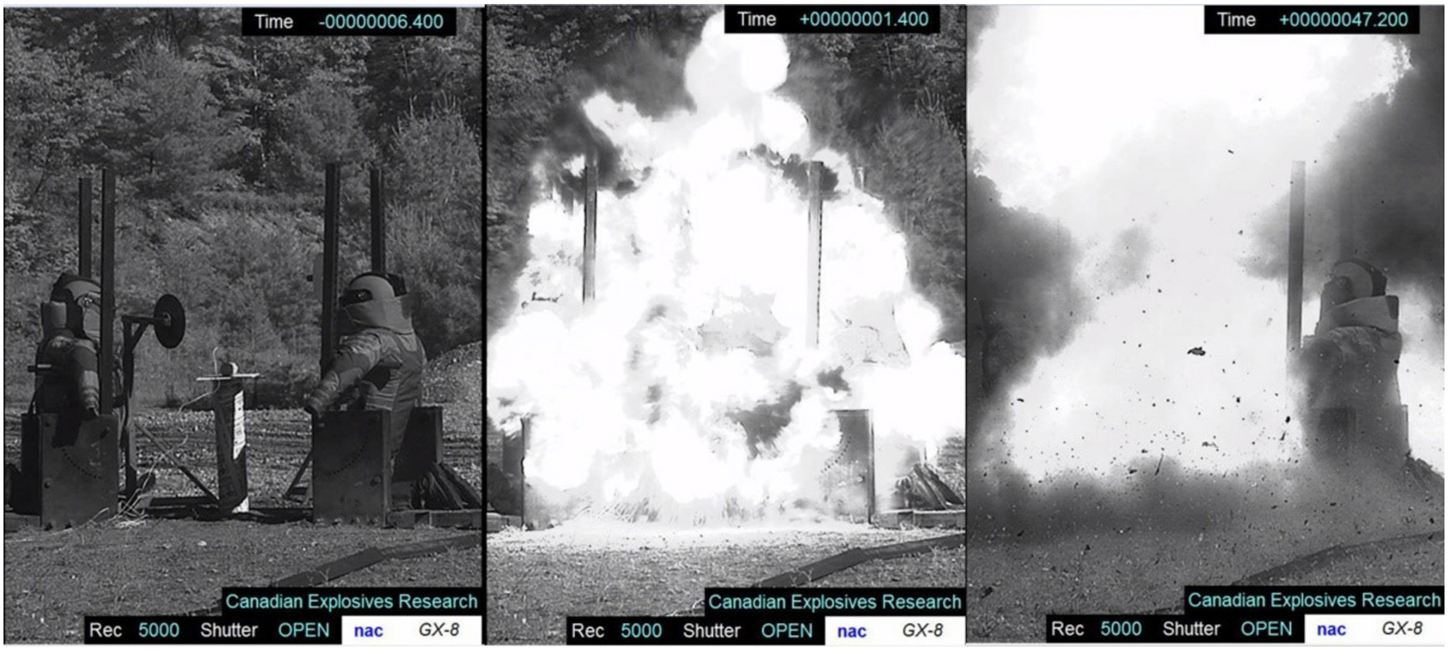

Figure 3: High speed video images of the NIJ 0117.01 blast overpressure test (0.567 kg C4 explosive, standoff 0.6 m – kneeling position). Two mannequins used for more data. Tests were conducted at the Canadian Forces Base Petawawa, under the leadership of the Canadian Explosives Research Laboratory and the supervision of Intertek auditors.

dynamic field of view tests (Figure 5) evaluate the appropriate integration of the helmet with the suit and protective plates. These tests ensure that the visual field is not blocked by suit components, such as the collar or frontal plates. Visor optics and visor fogging evaluations are also included in NIJ 0117.01.

Figure 4: NIJ Static FOV apparatus – helmet fitted on a headform and tested at various angles.

Figure 5: NIJ Dynamic FOV test – Head and Body motion with volunteer

The NIJ 0117.01 also includes requirements related to ergonomics, the number of sizes, maximum weight, label legibility, etc. Certification to the NIJ standard thus provides a clear independent bomb suit model evaluation against test methods relevant to EOD. All tests must be conducted by NIJ approved test laboratories selected by the certification organization, thereby saving procurement agencies from having to rely on supplier credibility or being forced to assess diverse test reports and data. Indeed, a single all-encompassing third-party test report addressing all standard requirements is provided by the certification organization, once all testing is completed.

Beyond the NIJ Standard: Other Relevant Requirements

The NIJ 0117.01 standard only represents a starting point, so that procurement agencies must consider other requirements when selecting bomb suits. In addition to quantitative blast overpressure (discussed above), which should be based on sufficient data points and involve head acceleration, ear and chest overpressure, other suit features, not necessarily directly related to protection, should also be mandated. For instance, one could consider that beyond meeting the minimal fragmentation protection requirements from the standard through controlled laboratory tests, a bomb suit can be evaluated against realistic fragmentation and blast devices in order to assess how the personal protective equipment holds together and resists fragmentation or other damage through dedicated, repeatable and controlled field tests [8]. Fragmentation protection levels to the head may also need to be increased as materials technology permits for enhanced protection to the head (face, helmet) over time.

In addition, there is often a need for personal cooling or ventilation, for technicians operating in harsh environments, given the inherent encapsulating nature of bomb suits. To that end, the ASTM F2371 performance test methodology [9] was developed, aiming at quantitatively evaluating the performance of personal cooling systems using so-called sweating thermal manikins subjected to high temperature (35°C, 50% relative humidity) conditions. This standard allows for testing of personal cooling systems (see Figure 6) when worn in conjunction with bomb suits, for a realistic and representative evaluation of the expected cooling benefits. This test methodology ensures that selected cooling options offer a true and proven quantitative benefit, beyond just a subjective feeling. Test conditions can have such a large influence on the cooling power provided by personal cooling systems, that relying on a standardized method is critical for a proper comparison of offered models.

While the NIJ standard only requires bomb suits to be available in at least three sizes, no specific requirements are included to determine the range of body sizes they should accommodate. It is recommended to accommodate at least the 5th percentile female to 95th percentile male, based on relevant anthropometric data.

In addition to sizing requirements, ergonomics should be evaluated beyond the limited NIJ basic simulated scenarios. Also, user comfort, while not explicitly mentioned in the NIJ standard, is critical. As an example, user comfort can be significantly enhanced through carefully crafted helmet retention systems that may involve adjustable and/or inflatable liners for an optimal fit [10].

Also of great importance, bomb technicians need to communicate safely when downrange near an explosive device. As such, all electronics within the suit and helmet must meet highly stringent military standards for electromagnetic compliance (emissions and susceptibility), as opposed to the less stringent industrial standards. EOD ensembles must also provide proper lighting to work in dark areas and may even need to provide video recording options for the purpose of forensics and sharing information with the command post.

Figure 6: Personal cooling system tested in conjunction with a bomb suit against the requirements of the ASTM F2371 test methodology. Tests were conducted at the Institute of Environmental Research from Kansas State University.

Finally, purchasing agencies must ensure that bomb suit manufacturers provide long-lasting, high quality and reliable products, with strong customer support. The NIJ manufacturing facility audit plays an important role for this aspect. Other accreditations of the product, such as CE markings, RoHS compliance and some regional standards may also apply for bomb suits to be procured and used in certain countries.

Discussion

The release of the NIJ 0117.01 standard for public safety bomb suits in 2016 empowered government agencies and EOD end-users to have confidence in the suitability of bomb suits they may select. Certified bomb suits according to the standard should meet all relevant protection and performance requirements for EOD. Prior to the release of this standard, one had to rely on reports provided by manufacturers based on how they tested their products. Legacy test methods were not standardized and oftentimes not applicable to EOD scenarios. On occasion, some manufacturers misrepresented the performance of their suit or even manipulated the test data to make favorable performance claims. Such unethical activity jeopardizes operator safety when left unchallenged during the competitive evaluation process.

While NIJ 0117.01 addresses the main blast threats (overpressure, fragmentation, impact, and heat), historical focus has been on overpressure and fragmentation, with limited emphasis on impact, especially for the head. Field experience in recent conflicts involving improvised explosive devices has highlighted the need for helmet impact protection to mitigate the very common occurrence of traumatic brain injury (arising from either blast or direct impact, [11]). The NIJ 0117.01 standard mandates a stringent set of head protection tests to ensure that EOD helmets provide high impact protection.

Given that the NIJ is a 'minimum' standard, purchasing agencies also have to take into account other requirements beyond NIJ 0117.01, such as, quantitative blast overpressure, CBRNe compatibility, electromagnetic compliance, personal cooling, communications, lighting, etc.

Bomb suit certification to the NIJ 0117.01 standard is the only way to ensure fully independent, comprehensive and reliable testing/validation of bomb suit performance against the most relevant EOD threats. Certification also ensures bomb suits and helmets are built as per documented manufacturing processes that are audited independently on a regular basis by an officially appointed and accredited organization.

In parallel though, the end-user community, government authorities and industry must continue to improve the standard and test methods, as protective materials and other technologies advance, or threat conditions evolve. The introduction of standard performance requirements and test methods permits for bomb suits to be officially certified, providing a 'seal of approval' that the particular product can be trusted to perform according to the standard. One must keep in mind that the **NIJ standard is a baseline standard, with some key functional requirements not currently being covered and requiring that they be specified explicitly in procurement requirements**.

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Dr. Makris is VP of Research, Development & Engineering and Chief Technology Officer at Med-Eng, which is a brand of The Safariland Group. He holds Masters and Ph.D. degrees in Mechanical Engineering, specializing in explosions and protection against blast effects, with over 30 years of related experience. He has led numerous programs involving the design and development of advanced personal protective systems to protect against IEDs, landmines, and explosive threats. Dr. Makris and his team have also conceived and developed a number of person borne blast sensors to assist in quantifying individual blast exposure under diverse operational circumstances and guide improvements in design, medical understanding and optimization of Techniques, Tactics and Procedures. Dr. Makris has been an active member of several equipment performance standards, including the NIJ Bomb Suit standard, NATO, UN working groups and a member of the IABTI Advisory Board.

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Dr. Dionne holds a Ph.D. in Mechanical Engineering from McGill University with over 20 years expertise in the fields of numerical simulations of detonations, blast waves and combustion. Since joining Med-Eng in 2000, he has been involved in numerous projects including explosive tests on demining and bomb disposal personal protective equipment, performance testing of personal cooling systems, blast dosimeters and blast mitigation seats. Dr. Dionne manages a group of R&D engineers and technologists dedicated to research related to all Med-Eng products. He has significantly contributed to the development of the National Institute of Justice NIJ 0117.01 standard for Public Safety Bomb Suits and he is currently leading the ASTM Working Group on the development of quantitative blast overpressure test methodologies for bomb suits. During the 2004 Personal Armour Systems Symposium, taking place in The Hague, Netherlands, Dr. Dionne received the Young Talent Award, recognizing his contribution in personal protection against blast.

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