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A Methodology to Assess Lethality and Collateral Damage for Nonfragmenting Precision-Guided Weapons

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A methodology was developed to assess lethality and collateral damage for the Focused Lethality Munition (FLM) program. FLM is a new nonfragmenting, precision-guided weapon with damage effects mechanisms that differ from the principal fragmentation damage effects for traditional weapons. To date, guidelines to determine lethality, based on mannequin test data, have not been articulated for nonfragmenting warheads such as FLM. Medical and military documentation was surveyed to derive lethality criteria for four FLM damage effects mechanisms and establish guidelines to address combination effects. The criteria were successfully applied to assess FLM military utility and preliminary validation of the procedures was conducted. Future plans include further augmentation of the model as additional data from program office continuation testing and operational weapon use become available.

Key words: Lethality; collateral damage; mannequin test data; focused lethality weapon; wound severity assessment.

The Focused Lethality Munition (FLM) program was conducted to assess the military utility of a focused-lethality precision-guided weapon. In the modern urban battle space, adversaries routinely place legitimate military targets near civilians or objects such as hospitals and churches protected under the Law of Armed Conflict. The ability to use air power for targets requiring minimal collateral damage is currently limited by the weapon fragmentation effects of available air-to-ground weapons, which can cause significant collateral damage. The FLM weapon was designed specifically to address high-value target prosecution, while minimizing collateral damage outside the focus area.

The FLM weapon combines two technologies to offer a more localized kill mechanism compared with the current steel case warhead, which has a fragmentation effect of 2,000 feet or more.[1] First, the multiphase blast explosive technology uses tungsten fill to increase the explosive weight and enhance near-field blast, as compared with conventional high-explosive fills. Second, the case surrounding the tungsten fill is composed of carbon fiber, which requires less energy to rupture than a comparable steel case. Upon detonation, the composite breaks into small, nonmetal fibers, thereby minimizing warhead fragmentation effects.

The FLM warhead is integrated into the Small Diameter Bomb I in place of the current warhead. The FLM warhead has the same weight, center-of-gravity tolerances, and outer mold line as the Small Diameter Bomb I, and operators use the same mission planning tools. The only modifications include incorporation of FLM weaponeering characteristics and collateral damage estimation calculations.

Science Applications International Corporation (SAIC) provided FLM assessment support to the United States (U.S.) Central Command from February 2007 through May 2008 under the Trusted Agent contract, with weaponeering expertise from the Decisive Management Professionals International (DMPI) subcontractor. The assessment team collected FLM lethality, collateral damage, and accuracy data during five static detonation events at Eglin Air Force Base, Florida, and 11 F-15E live-fly events at White Sands Missile Range, New Mexico. Primary data sources included human surrogates (i.e., full-weight mannequins, gel men, wooden dummies, and blast test devices) arranged in operationally realistic scenarios (*Figure 1*).

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Figure 1. FLM test setup

Problem description

Mannequins and blast test devices provide a readily available and cost-effective mechanism to address damage incurred during weapons tests. However, they do not provide a definitive means to determine lethality because mannequins are not living. Some damage can be observed (e.g., severed limbs). Many other types of injuries are not directly visible (e.g., internal injuries) and must be inferred to estimate the impact on lethality. To date, guidelines to determine lethality, based on mannequin data have not been articulated for nonfragmenting warheads such as FLM. Whereas the principal damage effects mechanism for traditional weapons is fragmentation, FLM damage results from a combination of other factors:

- Blast pressure impulse exerts G-forces on the body that can damage the spine, neck, and appendages.
- Blast overpressure can compress and damage air-filled structures, such as the lungs, ears, and gastrointestinal tract.
- Thermal effects can burn the skin and respiratory structures.
- Secondary weapon component debris, though minimal for FLM, can penetrate the organs and soft tissues.

To assess FLM military utility, a set of lethality guidelines was developed and applied for nonfragmenting warheads, based on research of medical and military literature.

Development of the solution

To develop a methodology to determine lethality for nonfragmenting weapons, the definition of a "serious/lethal" wound was first tackled. The Joint Munitions Effectiveness Manual (JMEM) Weaponeering System, the standard U.S. Armed Forces weaponeering tool, does not directly define a serious/lethal wound (JTCG-ME 2006; DIA 2003). However, it is widely accepted throughout the targeting and assessment community that *serious/lethal* is a wound category between the JMEM *serious* (i.e., one that requires hospitalization) and *lethal* (i.e., one that causes immediate death) categories. Thus, a serious/lethal wound is characterized by sufficient injury to cause death within 4 hours of the kinetic event when competent medical attention is unattainable.

Second, attention turned to the Department of Defense (DoD) severity scale to identify the numbers and types of severity categories needed (Chairman of the Joint Chiefs of Staff 2006). The DoD severity scale is used to describe personnel injury during battle damage assessments by the DoD. The DoD scale classifies the severity of human wounds into one of five categories:

- deceased (lethal)
- very serious (life is imminently endangered)
- serious (immediate concern, but no imminent danger to life)
- incapacitated (hospitalization required)
- not seriously injured (no wounds or minor injuries that do not require hospitalization)

A similar five-category scale was developed for FLM purposes: *lethal*, *severe*, *moderate*, *light*, and *no injury* (Rows A and B in *Figure 2*). For FLM assessment purposes, the DoD category for *not seriously injured* was subdivided into *light* and *no injury* to facilitate calculation of the collateral effects radius (distance

A	**FLM Scale**	**Lethal**		**Severe**	**Moderate**	**Light**	**No Injury**
B	**DoD Scale**	Deceased	Very Serious	Serious	Incapacitated	Not Seriously Injured	
C	**Distance Propelled**	≥ 10 feet		> 5 feet but < 10 feet	1 to 5 feet (depending on impact geometry)		
D	**Blast Overpressure Percent Lung Contusion**	Severe Area > 50%			Moderate Area > 10% but < 50%	Slight and Trace Area > 0% but < 10%	No Injury Area = 0%
D	**Blast Overpressure Qualitative Severity Level**	Very serious injury/lethality predominant		Some severe injury	Some moderate injury	Injuries greater than trace unlikely	Injury unlikely
E	**Thermal Injury Severity**	Major 1^{st} / 2^{nd} degree > 25% 3^{rd} degree, > 10%		Moderate 1^{st} / 2^{nd} degree 15 to 25% 3^{rd} degree, 2 to 10%		Minor 1^{st} / 2^{nd} degree < 15% 3^{rd} degree, < 2%	No thermal injury
F	**Required Secondary Debris Wound Treatment**	Immediate medical care for survival or penetrates skull		Less urgent surgery for survival	Simple medical care in treatment facility	Self-help treatment	

Figure 2. FLM severity scale components

associated with $P \leq .10$ of serious/lethal wound to a standing human) and the risk estimation distance (distance associated with $P \leq .001$ of human injury, considering posture, warning level, and terminal ballistic condition of warhead). Further, the DoD categories for *deceased* and *very serious* were combined into a single category representing *lethal*, on the basis of the JMEM description of serious/lethal wounds. All of the categories were color coded, with red for *lethal* and blue for *no injury*, for ease of interpretation.

Third, the medical and military literature was researched to clarify the individual damage effects mechanisms for FLM and to establish criteria for each of the five categories in the FLM wound severity scale.

Blast pressure impulse effects. Blast pressure impulse is the primary damage effect mechanism for FLM. Observations of full body translation caused by the pressure impulse of kinetic events in recent combat operations indicate a relationship between the distance the human body is propelled and the severity of the injury incurred (JTCG-ME, 2006).[2] Thus, the FLM wound severity ratings were linked to distance propelled to provide criteria for assessing impacts of blast pressure impulse (Row C in *Figure 2*).

- Humans propelled a distance of 10 or more feet suffer sufficient G-forces to produce very serious or lethal injury, corresponding to the FLM *lethal* category. The cause of death in these instances is cardiac arrest, severe neck or spinal injury, severe brain trauma, or traumatic amputation of a major limb (arm or leg).
- Humans propelled more than 5 but less than 10 feet suffer serious injury, corresponding to the FLM *severe* category. Injuries may include brain concussion, hemorrhaging of the brain and vital organs, severe ligament damage, and bone fractures.
- Humans propelled between 1 and 5 feet either suffer no injuries or are incapacitated for a short period, depending on the geometry of the impact. The injuries sustained correspond to the FLM *moderate*, *light*, or *no injury* categories.

The primary factor differentiating among these three categories is the portion of the body taking the brunt of the impact. A higher severity rating of *moderate* is assigned if the body falls head or face first or impacts another stationary object such as a wall or vehicle. In some rare cases, humans propelled less than 5 feet receive serious injury requiring extended medical attention (often associated with blunt trauma from impacting a hard surface or object).

Blast overpressure effects. Blast overpressure is a secondary human lethality mechanism for FLM. Blast overpressure produces a crushing effect on the human body, potentially causing severe injury to the lungs, ears, other organs, and soft tissue (Pennardt 2007). Blast overpressure lung injury creates contusions that cause hemorrhaging, swelling, and fluid accumulation, leading to labored and progressively less efficient breathing (De Lorenzo and Porter 1991). Additional symptoms include disturbances in consciousness, small strokelike symptoms, and bloody sputum. Use of cardiopulmonary resuscitation or mechanical respira-

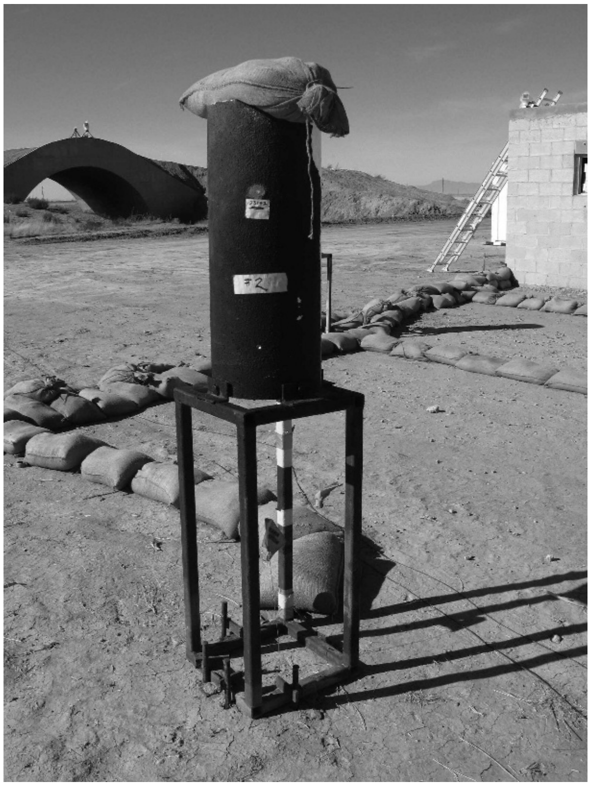


Figure 3. Blast test device

tors on individuals with blast overpressure lung injuries may release air bubbles into the bloodstream, which can cause severe injury or death if they reach the heart or brain.

Blast test devices are frequently used to gather blast overpressure data during weapons effects tests. A blast test device is a rigid cylindrical device about the size of a human torso that measures external pressure loading due to blast overpressure *(Figure 3)*. Measurements obtained from four pressure transducers evenly spaced around the circumference of the cylinder at midheight represent the pressure felt on the chest, right side, left side, and back of a human thorax. Each measurement is saved as a separate data file constituting a pressure-versus-time trace for a given location on the blast test device. Data are then entered into the INJURY 8.2 software program to predict lung injury from blast overpressure.[3]

The FLM wound severity ratings were correlated to two different types of blast overpressure estimates provided by INJURY 8.2 (Row D in *Figure 2*). Qualitative estimates provide labels for an easy-to-read designation of the severity of injury expected. Quantitative estimates provide probabilities associated with the degree of lung contusion expected, as characterized by the percentage of total lung surface area contused (directly related to lung hemorrhage).

Table 1. INJURY 8.2 output for blast overpressure damage

	INJURY 8.2 output (probability)			
Example	**Severe**	**Moderate**	**Slight/trace**	**No injury**
Case 1	0.00	0.01	0.16	0.84
Case 2	0.05	0.42	0.23	0.30
Case 3	0.40	0.40	0.15	0.05

In general, the FLM severity category associated with the highest INJURY 8.2 probability indicates the most likely severity of injury, following the JMEM 50-percent lethality criterion rule:

- Any category associated with an INJURY 8.2 probability greater than .50 was always selected as the final severity category (e.g., *no injury* for Case 1 in *Table 1*).
- In cases where none of the probabilities exceeded .50, the team located the largest probability and inspected the probability in the next most severe category. If the combined values produced a probability greater than .50, then the more severe category was selected. If the combined values failed to produce a probability greater than .50, then the category with the largest value was selected for the final rating (e.g., *moderate* for Case 2 in *Table 1*).
- In the case of a tie, the more severe category (e.g., *severe* for Case 3 in *Table 1*) was always selected.
- If the INJURY 8.2 *severe* category met the criteria described in the preceding paragraph, an FLM rating of *lethal* was always assigned if the probability was .50 or greater; otherwise, the FLM rating remained at *severe*.

Thermal effects. Thermal is a secondary human lethality mechanism for FLM. The severity of thermal injury or burns is characterized by (a) degree, based on the severity of the tissue damage that may extend to the underlying fat, muscle, or bone; and (b) amount of body surface area involved. Burn degree is designated as either *first-degree* (redness and swelling in the outermost layers of skin), *second-degree* (redness, swelling, and blistering, with damage extending beneath epidermis to deeper layers of skin), or *third-degree* (full-thickness burn that destroys the entire depth of skin, causing significant scarring).

Amount of body surface area involved is expressed in terms of the "rule of nines" used by health-care professionals for adult burn patients (Arizona Burn Center 2008). For the rule of nines, each arm with its hand included constitutes 9 percent of the body surface area; the front of each individual leg with its foot is 9 percent; the back of each individual leg with its foot is

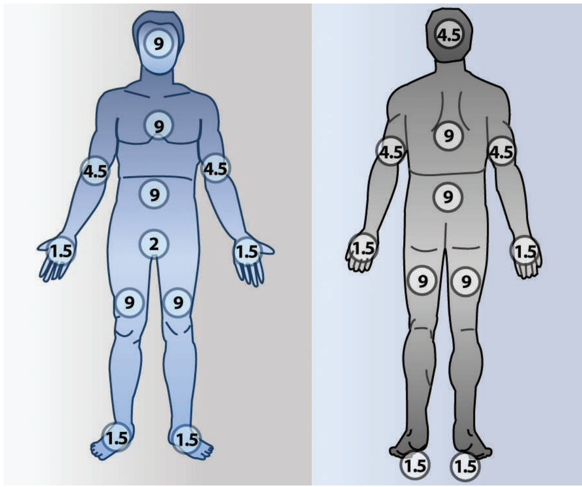


Figure 4. Weighted rule of nines

9 percent; the chest is 9 percent; the abdomen is 9 percent; the back is 9 percent; the buttocks are 9 percent; the face, back of the head, and neck are 9 percent; and the genital area (perineum) is 1 percent.

Burns involving the hands, feet, face, eyes, ears, or genitals are considered especially critical because the skin is thinner. To account for this fact, a weighting scheme was applied to the traditional rule of nines *(Figure 4)*. Whereas hands and feet are normally lumped in with their limbs, ratings were assigned for each limb and additional values for each hand or foot. Thus, maximum values of 9 percent were applied to each arm (4.5 percent for the front and 4.5 percent for the back), 3 percent to each hand (1.5 percent for the front and 1.5 percent for the back), 18 percent to each leg (9 percent for the front and 9 percent for the back), and 3 percent to each foot (1.5 percent for the top and 1.5 percent for the bottom). The genitals and the face were assigned double values—9 percent for the face alone and 2 percent for the genitals. Altogether, the weighting permitted an increase of up to 17.5 percent of the total body surface area burned if critical body parts were affected.

Taken together, the burn degree and percentage of body surface area affected are used to identify burn severity:

- Minor burns are (a) first- or second-degree burns covering less than 15 percent of an adult's body or (b) third-degree burns covering less than 2 percent body surface area. Minor burns, which may be treated at home or in a doctor's office, are linked to an FLM severity rating of *light* (Row E in *Figure 2*).
- Moderate burns are (a) first- or second-degree burns covering 15 to 25 percent of an adult's body or (b) third-degree burns covering 2 to 10 percent body surface area. Moderate burns, which should generally be treated at a hospital, are linked to FLM severity ratings of *severe* or *moderate*.
- Major burns are (a) first- or second-degree burns covering more than 25 percent of an adult's body or (b) third-degree burns covering more than 10 percent body surface area. These burns are the most serious and should be treated in the specialized burn unit of a hospital, correlating to an FLM severity rating of *lethal* (Thivierge 2008).

Secondary debris penetration. A tertiary human lethality mechanism for FLM is secondary debris, either from weapon components or objects in the area (e.g., vehicles, buildings, and other objects). Secondary debris may contribute to lethality within the target area; however, there are no reliable methods or models to predict the effects of secondary debris for all target environments. The criteria in Row F of *Figure 2* were developed for FLM severity ratings of secondary debris penetration.

Criteria for the *lethal* category were based on the following considerations. Wounds that penetrate the skull are usually immediately lethal. Very serious wounds that require immediate treatment include injuries that disturb consciousness, breathing, the airway, or circulation; major injuries to the head or torso; or major hemorrhaging. For example, major hemorrhaging is generally the imminent threat for most wounds involving the abdomen and chest because they house the vital organs (Owen-Smith 1981). Shock, which is considered very serious and requires immediate treatment, can arise from major muscle damage, especially when associated with a major fracture, severe burns, major hemorrhaging, multiple wounds, and pericardial injuries.

The remaining FLM severity categories represent less serious injuries. Injuries that require surgery or intensive medical care, but will not cause death if delayed, received FLM ratings of *severe* (e.g., weapon component debris penetrates the abdomen but does not affect any internal organs). Injuries that require medical care, but can be managed by simple treatment and dressing provided in a medical care facility, are categorized as *moderate* (e.g., abdominal debris that causes moderate bleeding). Injuries that can be treated by self-help are categorized as *light* (e.g., small surface wounds) (Owen-Smith 1981).

Finally, after researching the individual damage effects mechanisms for blast pressure impulse, blast overpressure, thermal, and secondary debris penetration, guidelines were established for estimating combined effects. The postdetonation condition of an individual is not always caused by only a single mechanism. Combinations of effects may cause multiple injuries that can lead to a higher severity rating than would be associated with any one injury by itself. The following factors were considered when addressing combined effects for mannequins with multiple injuries:

- amount of potential blood loss
- location of injuries, with the head, chest, abdomen, and genitals being the most vulnerable in the case of blunt trauma and penetration injuries
- head injuries combined with other injuries
- injuries affecting the airway or respiratory system
- injuries combined with major burns

For the FLM program, the overall severity level was assigned on the basis of the highest severity level of the individual sustained injuries. For example, if blast pressure impulse was *moderate* and thermal injury was *severe*, the overall severity rating was *severe*. If there were multiple injuries at the same severity level, that severity level was assigned. The question of whether multiple injuries at the same severity level translate into a higher overall severity level has not been adequately resolved.

Criteria application

After each FLM test event, photographs of the test site were taken for comparison to pretest setup, displacement of the mannequins from their original positions measured, and extent of any damage (e.g., burns, punctures, missing limbs) thoroughly documented to enable application of the preceding criteria. The criteria for blast pressure impulse, thermal damage, and combination effects resulting from these two damage effects mechanisms were successfully applied. Data for blast overpressure were collected but not used because of data corruption. The collected data did not meet the quality parameters for input into INJURY 8.2. Secondary debris effects were documented for completeness but not included in the scoring because of the unpredictable and unrepeatable nature of secondary debris.

Of the two damage effects mechanisms assessed, thermal presented the most challenges. Application of the criteria for blast pressure impulse was relatively straightforward because it primarily involved simple measurement of the distance each mannequin was propelled. Assessing thermal damage to the skin on mannequins entailed determining the degree of the burn, the percentage of body surface area affected, and the specific body parts burned. FLM thermal injuries may result from fire associated with the explosion or from the tungsten fill of the warhead. Tungsten can potentially cause significant thermal injury when it

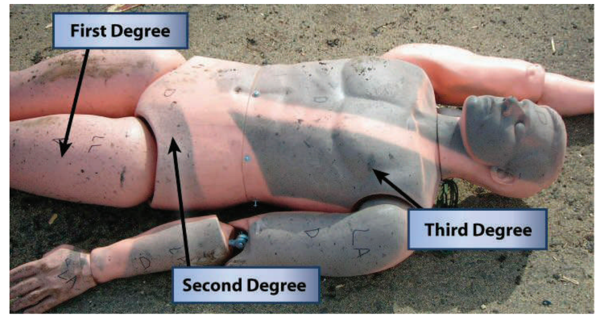


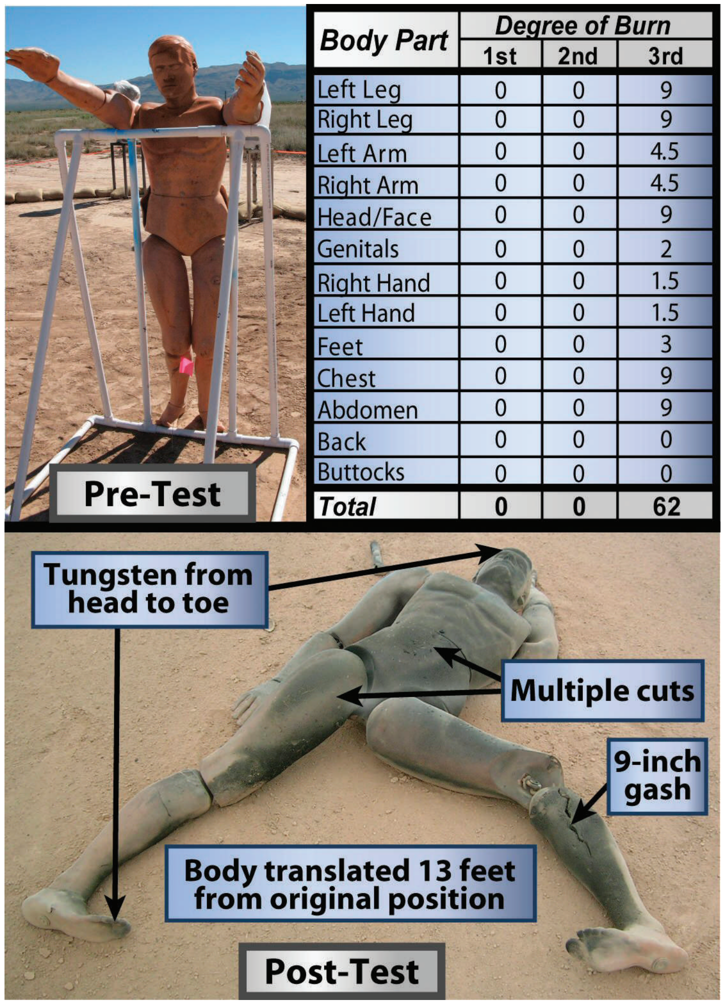
Figure 5. Burns in mannequins

impacts the skin because of the high temperature and velocity of the tungsten at the time of impact. The chief difficulty was translating guidelines developed for human burns to evidence obtained from mannequins, which cannot exhibit the same thermal effects as humans because they do not have skin.

During the initial static tests, primary reliance was on observations of thermal effects in commercially butchered pigs to identify applicable thermal guidelines for mannequins. These guidelines were based on the professional expertise of Reddoch Williams, M.D.[4] By his estimations, if the skin was covered with a significant layer of tungsten (i.e., no skin visible underneath), the burn was classified as third degree. A moderate layer of tungsten (i.e., skin barely visible underneath) led to a classification of second-degree burns. A light dusting of tungsten (i.e., skin clearly visible underneath) was classified as first-degree burns.

When applied to mannequins, these guidelines translated into third-degree burns if the surface of a mannequin was charred with the outer layer of rubber cracking. When the surface of the mannequin presented a gritty gray-to-black appearance to the point where the discoloration and grit could not be removed by wiping, the mannequin was characterized as having second-degree burns. When the surface of the mannequin presented a gritty gray-to-black appearance, but the discoloration and grit could be removed by wiping, the mannequin was characterized as having first-degree burns. *Figure 5* provides examples for each degree of burn.

When assigning thermal severity ratings, the severity level was increased if the injuries were associated with the respiratory system or eyes. Burns to the faces of mannequins were recorded and assessed for airway burns by degree of charring to the mouth and nose and for burns to the eyes by degree of charring or tungsten on the eye area. There was no method to directly determine thermal inhalation and vascular injuries to mannequins.



Body Part	Degree of Burn		
	1st	2nd	3rd
Left Leg	0	0	9
Right Leg	0	0	9
Left Arm	0	0	4.5
Right Arm	0	0	4.5
Head/Face	0	0	9
Genitals	0	0	2
Right Hand	0	0	1.5
Left Hand	0	0	1.5
Feet	0	0	3
Chest	0	0	9
Abdomen	0	0	9
Back	0	0	0
Buttocks	0	0	0
Total	**0**	**0**	**62**

Figure 6. Sample validation slide

Criteria validation

Two methods were used for preliminary validation of the criteria and assessment procedures. Both techniques provided considerable support for the validity of the FLM severity criteria.

Logistic regression analysis. First, the results of a logistic regression model provided initial confirmation for the legitimacy of the lethality evaluation criteria. The logistic regression analysis was conducted to provide supporting evidence for the lethality/nonlethality cutoff distance the team estimated based on visual observation of the outcome for each mannequin (i.e., criteria were applied to derive a lethality rating for each mannequin and then the results were visually inspected to determine the distance representing the cutoff between lethal and nonlethal). For a more objective, mathematical approach, a logistic regression analysis was completed—a statistical technique was used to predict lethality, based on distance from the impact. The analysis included 64 FLM test articles (32 designated as lethal and 32 designated as nonlethal). The mathematical model obtained from the logistic regression correctly categorized 59 of 64 cases (92 percent). Further, the predicted cutoff distance between lethality and nonlethality exactly matched the distance determined on the basis of visual inspection alone. The orderliness of this outcome lends credence to the validity of the underlying procedures used to determine lethality.

Independent application of criteria. Second, an independent verification of criteria application was conducted to address validity. Two people with no previous connection to the FLM program were asked to provide independent lethality ratings for a sample of 20 mannequins (12 *lethal*, 1 *severe*, 2 *moderate*, 2 *light*, and 3 *no injury*). The independent assessors had several days to review the FLM severity criteria and descriptions before individually completing the validation task. A briefing provided background information on the test setup, the targets, and the collateral concerns; depictions of the pre- and post-test layouts; and a separate slide for each mannequin with pre- and post-test photographs, descriptions of injuries, distance the mannequin was propelled, and thermal injury data (degree of burn, percentage of body surface area affected, and body parts burned) *(Figure 6)*. The independent assessors provided ratings for blast pressure impulse, thermal effects, and overall lethality as well as descriptions of their rationale for each rating.

The *kappa* statistic for inter-rater agreement was .76, a value that indicates "excellent" agreement among the three sets of ratings for the sample of 20 mannequins (Fliess 1981). When disagreements occurred, the independent assessors tended to assign more severe ratings. In particular, the independent assessors experienced difficulty deciding whether to assign *moderate*, *light*, or *no injury* ratings when the body was propelled 1 to 5 feet. They had trouble evaluating the critical deciding factor of impact geometry for these cases, in part because it was difficult to discern from photos alone whether the body had been thrown face first or simply fell forward after the blast.

Future plans

The criteria provided a defendable and repeatable approach to determine lethality for nonfragmenting, precision-guided weapons such as FLM. The FLM operational manager at the U.S. Central Command was able to use the final report, delivered in May 2008, to provide a military utility recommendation for the FLM weapon and develop future plans. As additional data from program office continuation testing and operational weapon use become available, it is expected that the methodology will be augmented. The methodology presented in this article represents the preliminary development, application, and validation of procedures and guidelines. With additional research and data, the methodology can easily be expanded to provide robust and repeatable procedures. Several focus areas for the future include:

- development and verification of more concrete guidelines for thermal effects
- instrumentation with blast test devices that meet specifications for use with INJURY 8.2, with attention to proper setup (e.g., anchoring to prevent tip over during blast; coating of pressure sensors and wires for sufficient protection against flames, heat, tungsten, particles, and light)
- use of autopsy reports for definitive determination of lethality
- more robust validation of lethality determinations (including initial decisions regarding damage effects and criteria application)
- overall enhancement of criteria to boost specificity and eliminate as much subjectivity as possible
- verification of the full model with all four damage effects mechanisms and combination effects ❑

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DAVID FAULKNER, the founder and president of the DMPI defense consulting firm, has more than 20 years of experience in DoD senior leadership and targeting positions. He has a master of arts degree in Near Eastern studies from the University of Arizona and a bachelor of science degree in physics from Appalachian State University. Mr. Faulkner applied his expertise in munitions effectiveness and employment to assist in development of the FLM lethality criteria.
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Endnotes

[1]The Air Force Research Laboratory Munitions Directorate at Eglin Air Force Base, Florida, developed both FLM technologies.

[2]Based on extensive operational observations of lethality induced by full body translation, per U.S. Central Command Director of Joint Targeting and Assessment.

[3]INJURY 8.2 is a medical research product developed by the U.S. Army Medical Research and Materiel Command's Military Operational Medicine Research Program.

[4]Reddoch Williams, M.D. (E-mail: Reddoch@aol.com). Dr. Williams received formal training at Emory University and has experience treating human burn wounds. At the time of the FLM test, he served as a Flight Surgeon, Air Force Reserve, attached to the Command Surgeon's office at Headquarters Air Force Special Operations Command.

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