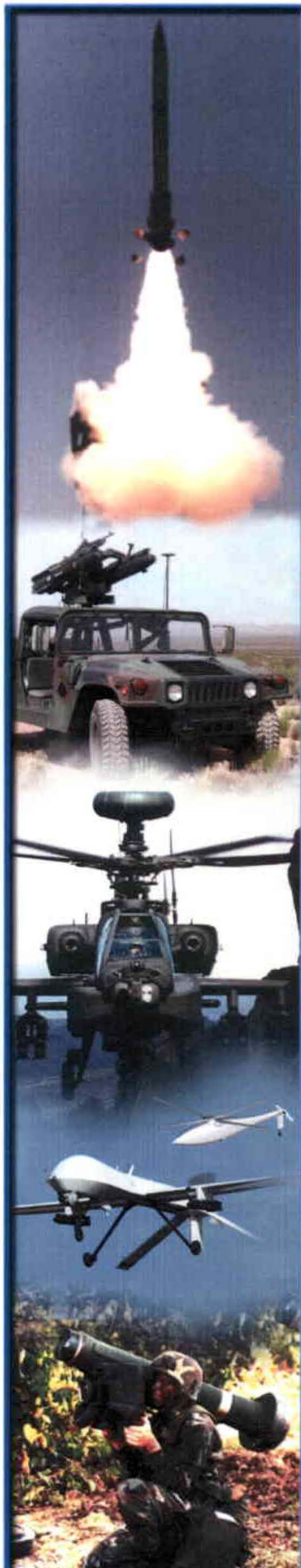

TECHNICAL REPORT RDMR-SS-11-01

VERIFICATION AND VALIDATION PLAN FOR THREE-DIMENSIONAL PROBABILITY OF INCAPACITATION METHODOLOGY FOR MASONRY STRUCTURES (3DPIMMS)

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13. ABSTRACT ***(Maximum 200 Words)***
This report describes the Verification and Validation (V&V) plan for Three-Dimensional Probability of Incapacitation Methodology for Masonry Structures (3DPIMMS) which is used to support lethality analysis of various Army missile systems. 3DPIMMS is developed and maintained by the System Simulation and Development Directorate (SSDD) of the Aviation and Missile Research, Development, and Engineering Center (AMRDEC) at Redstone Arsenal, Alabama. The historical lineage of the tool and its components are discussed. The current tool capabilities for modeling incapacitation are discussed along with the analyses which will be performed to support V&V. Acceptability criteria are described.

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I. PURPOSE

This report describes the Verification and Validation (V&V) plan for Three-Dimensional Probability of Incapacitation Methodology for Masonry Structures (3DPIMMS) which is used to support lethality analysis of various Army missile systems. The U.S. Army Test and Evaluation Command (ATEC) requires V&V of models that will be used for its evaluation of weapon systems.

II. BACKGROUND

3DPIMMS is developed and maintained by the System Simulation and Development Directorate (SSDD) of the Aviation and Missile Research, Development, and Engineering Center (AMRDEC) at Redstone Arsenal, Alabama.

A. Historical Development

3DPIMMS is descended from models developed by the U.S. Army Ballistics Research Laboratory (BRL), now the Army Research Laboratory (ARL). It was originally developed by the University of Alabama in Huntsville (UAH) Research Institute under contract to SSDD at the AMRDEC.

1. PICODE and PINFIB

The PICODE and PINFIB programs were designed and developed by BRL. The PICODE program provides incapacitation probabilities for attacks on personnel inside masonry structures using impact fuzed munitions. The PINFIB program evaluates a program identical to that of PICODE except that delay fuzed munitions are used for the attack. Computer Sciences Corporation (CSC) in Huntsville, Alabama, was placed under contract to produce the PIMMS program by merging or combining PICODE and PINFIB and to provide documentation for the new program, PIMMS [1].

The PINFIB program was used as the basic structure for the PIMMS program. Logic and algorithms peculiar to PICODE were placed in the existing PINFIB code. These were fully integrated into the PINFIB program logic to avoid producing a new program consisting of a collection of patches.

As a result, the PIMMS program is the integration rather than the attachment of PICODE and PINFIB. The PIMMS program retains both the capability and flexibility of PICODE and PINFIB. Its code is well commented, and it has convenient input data structure. Only minor improvements were made to the program logic provided to CSC. These changes were primarily cosmetic in nature.

2. PIMMS (2D)

What is now referred to as 2DPIMMS is the result of this integration of PICODE and PINFIB and was used for several years. It utilized a rough approximation for target personnel and a fragment density per area type of calculation in determining probability of incapacitation (Pi). The 2DPIMMS process is described as follows:

The room is filled with men for each analysis, each occupying a potential space for the randomly located man position. A cylinder of specified diameter and vertical cross-sectional area is used to represent a man. The 2DPIMMS setup of man locations is shown in Figure 1. A sequence of burst points at a fixed interval along the wall is evaluated in analysis of impact fuzed munitions. A matrix of burst points covering the room in the horizontal plane is evaluated when delay fuzed munitions are used. The 2DPIMMS burst point array is shown in Figure 2.

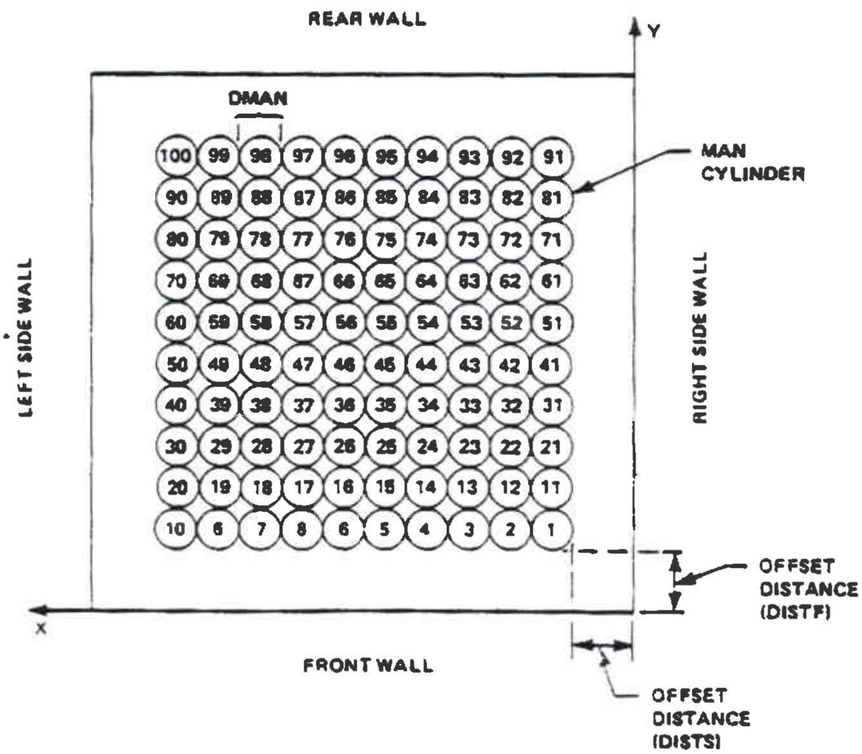

Figure 1. 2DPIMMS Man Locations [1]

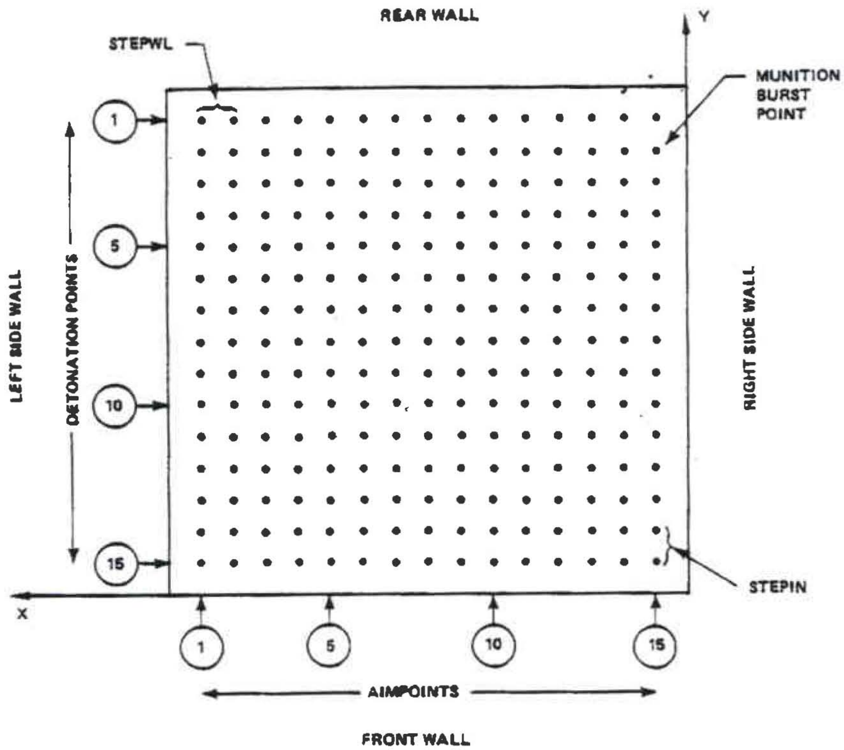

Figure 2. 2DPIMMS Burst Point Array [1]

Attack orientation or direction relative to the wall is an input value. Fragmentation data about the burst point are input in 5-degree zones relative to the attack or shot direction. For each munition burst point, an incapacitation determination is made for each man in the room. A man is considered incapacitated when struck by one or more lethal fragments. When this criterion is not satisfied, the man is considered undamaged by the burst. Both the number of incapacitated men and their room locations are stored for each munition burst point. Attacks on each wall of the room are evaluated. This is consistent with the Joint Technical Coordinating Group for Munition Effectiveness (JTCG/ME) methodology for analysis of direct fire muntions against personnel targets [2].

After the attack has been evaluated, Pi data is generated for each room wall. Pi for a randomly located man from a given burst point is computed as the ratio of the number of incapacitated men to the number of men in the room. Average and cumulative average probability of incapacitation data for a randomly located man are also provided for each wall attack.

The original fragmentation data source for the PIMMS model was taken from 3/8 inch plywood and 3/4 inch Celotex witness panels placed along the walls in the Military Operations in Urban Terrain (MOUT) room tests [3]. This has historically been used as the threshold filter for effective fragments. Those which perforated completely through the panels were deemed incapacitating and used for analysis. This data was collected by manually recording perforation locations or, more practically, data collection was performed photographically with the aid of a light table apparatus to illuminate the perforations by backlighting the witness panel.

Once data from all panels of a test were recorded, it was reduced into text format and then input into the code.

B. Current Development

The capabilities of 2DPIMMS were further improved upon by the AMRDEC's development of 3DPIMMS in 1997. It incorporated the use of Ballistics Research Laboratory Computer Aided Drafting (BRL-CAD) raytracing of fragments against ARL's Computerman wound ballistics model in a three-dimensional environment. This provided higher-fidelity lethality results by analyzing the fragments which would actually impact the man locations within the structure rather than simply relying on fragmentation density collected from the impact locations on the test wall panels.

Currently, 3DPIMMS includes the capability to use Computerman, Operational Requirement-Based Casualty Assessment (ORCA), Sperazza-Kokinakis (SK), and Ballistic Dose (BD) models for assessment of incapacitation due to fragmentation. Any or all of these models can be activated for a particular lethality assessment. Incapacitation criteria of different times and roles are available. A vast improvement over the cylinder used in 2DPIMMS, the 3D man geometry is most commonly used to represent a randomly-located man position within a room of some analyst-defined size. Its facing direction, grid spacing between positions, posture, and level of uniform/armor protection can also be changed.

As in 2DPIMMS, wall witness panel data from MOUT room tests remains a primary means of data input into 3DPIMMS. Perforation locations are collected and input similarly as before, but now a warhead detonation point is also needed for the creation of direction vectors in three-dimensional space. This is predetermined in the setup for the case of a static room test or it can be estimated from high-speed video or post-test inspection of the room in the case of a dynamic flight test. Once the fragment direction vectors are calculated, the mass and velocity distributions, material density, and shape factor can be set by the user.

An additional means of data input for 3DPIMMS is through the use of a Z-data file. It is a statistical representation of warhead fragmentation as described by the Joint Munitions Effectiveness Manual (JMEM) and is derived from arena testing. The Z-data file divides the fragments into polar zones from the nose of the warhead at 0 degrees to the aft end at 180 degrees. Each polar zone has its own fragment velocity range, fragment mass classes, and number of fragments in each mass class. A single shape factor is defined for all fragments represented in the file. Only the fragment material density needs to be set by the user.

3DPIMMS accounts for some statistical variation in the fragmentation data through its use of a Monte Carlo process. The analyst can define the number of repetitions and the code will make statistical draws from either the Z-data file or the mass and velocity inputs of wall panel data and perform the lethality analysis for each. When used, the Monte Carlo feature provides outputs for each individual repetition as well as the mean values.

Another data input source to 3DPIMMS is a Frag file which explicitly defines the unit direction vector, mass, velocity magnitude, shape factor, and density for each individual fragment to be used in the lethality analysis. This is generally not a primary data source due to the difficulty involved in creating this file format directly from test data. It is, however, easily generated from either the wall panel data or Z-data file inputs, and 3DPIMMS appends this Frag file data to the end of its output files. This data format effectively provides a clear record of the fragmentation data used in a particular analysis.

Regardless of the fragmentation data source, 3DPIMMS, by default, analyzes all potential warhead burst points inside the room for a given height horizontal plane. This is commonly used for most analyses in order to provide the system developer with sufficient data to optimize the warhead design's lethality. Specific burst points of interest, such as the exact detonation location from a particular test event, can also be selected for analysis when system trades are not being considered or when computational time is of concern.

3DPIMMS has the capability of inputting multiple fragment material types by allowing for different density and shape factor. Munition systems typically produce fragments of more than one material type; current testing and data collection methods can reliably distinguish between these. Input of multiple fragment materials eliminates error that would be introduced by approximating all fragments as having the same density and shape factor or by performing analysis of different fragment material types individually and then combining the outputs via a survivor sum rule or some other method.

C. Intended Use

The objective is to ensure that 3DPIMMS remains an accepted standard and state-of-the-art analysis tool for personnel incapacitation in the vulnerability/lethality/survivability and modeling and simulation communities. It allows for the use of a range of data input methods, incorporates several incapacitation models, and provides the capability to perform pre-test prediction, post-test evaluation, and parametric studies for analysis of weapon systems.

III. VERIFICATION AND VALIDATION APPROACH

According to Reference 4, verification is the process of determining that a model or simulation represents the developer's conceptual description and specifications and meets the needs stated in the requirements document. The verification process thereby establishes whether the model or simulation code and logic correctly perform the intended functions. Validation is the process of determining the extent to which a model or simulation accurately represents the real world phenomena from the perspective of the intended use of the model or simulation. In this section, an attempt will be made to formulate a plan of action that will be taken to effectively verify and validate 3DPIMMS for its use as an evaluation tool for incapacitation of personnel in MOUT structures.

3DPIMMS has undergone some V&V work in the past and this work will be drawn from for the current V&V effort. Additionally, a number of sensitivity analyses will be performed and comparisons will be made to other related models.

A. Previous V&V Work for Multi-Purpose Individual Munition (MPIM)

In support of the MPIM program in 1999, a V&V effort was undertaken to compare the capabilities of the newly developed 3DPIMMS with that of the older 2DPIMMS. The MPIM program was terminated and ATEC never officially accredited 3DPIMMS for use on the program.

This prior effort focused on the transition to the 3D version of the tool, confirming that it had properly maintained the functionality of the 2D version while updating the capabilities as discussed previously. 3DPIMMS has been used as a standard model in the intervening years and, as such, the present V&V effort will center on current tool capabilities instead of just its conversion from the legacy version.

B. Other Historical Uses of 3DPIMMS

3DPIMMS has been the default model used for personnel lethality analysis of numerous munition systems over the past two decades. These include Hellfire (FA, K2, K2A, K2B, M, N, P2A), Javelin, Tube-Launched Optically-Tracked Wire-Guided (TOW) Bunker Buster, Precision Guided Mortar Munition (PGMM), Hydra 2.75 inch, MPIM, Compact Kinetic Energy Missile (CKEM), Joint Common Missile (JCM), Griffin, Mid-Range Munition (MRM), Bunker Defeat Munition (BDM), Excalibur, and various other Army Technology Objective (ATO) and Science and Technology (S&T) programs.

3DPIMMS, in addition to the AMRDEC, has also been used by ARL, Army Evaluation Center (AEC), and Army Materiel Systems Analysis Activity (AMSAA) for Pi evaluation of weapon systems. It is accepted as a standard analytical tool in the MOUT community [5].

C. Planned V&V Analysis

During verification, the key variables to which the model are most sensitive are identified for test and analyses. Given the results of these, the subject matter experts validate whether the model provides proper output across the entire spectrum of valid data [4]. Several key components of 3DPIMMS will be the focus of the V&V effort. These include ensuring that the legacy capabilities are maintained, munition characteristics data are properly handled as inputs to the model, and the wound ballistics models provide correct and reasonable outputs.

1. Preservation of legacy capability of wall panel data input. As the original means of fragmenting munition data input, it is important to properly maintain the capability of analyzing MOUT room wall panel data directly for personnel lethality. 3DPIMMS should continue to include this historical competency from 2DPIMMS. Fragment direction vectors should be accurately determined from the munition detonation point and the fragment impact locations on the wall panels.

2. Proper use of Z-data files to throw fragments. The Z-data input is one of the major advancements of 3DPIMMS beyond 2DPIMMS and has become a primary means of conducting parametric analyses. It is important to verify that 3DPIMMS incorporates the fragments' masses, velocities, number, polar zones, shape factor, and material density correctly and according to the description in the JMEM. This also extends to the use of multiple Z-data files when different fragment materials are involved.

3. Proper implementation of Monte Carlo Z-data repetitions. When using the Monte Carlo feature with Z-data input, 3DPIMMS should execute random draws from the Z-data file to

initialize the fragmentation data to be analyzed for each repetition. Output from each repetition will be examined for statistical variation between the results of each random number draw to determine if they are indeed different for each individual draw. Mean outputs from a Monte Carlo run will be examined to ensure each repetition output is accumulated and averaged together correctly.

4. Proper use of Frag file input. Using this input method correctly to explicitly define the data for individual fragment can be confirmed visually for small numbers of fragments. It becomes impractical to input large numbers of fragments via this method. However, the Frag file itself provides an excellent means of verification of the wall panel data and Z-data inputs that are used in an analysis. Since a Frag file is generated in output for each 3DPIMMS run, including the individual Monte Carlo repetitions, it is simple to then take this Frag file as an input to re-run and verify that the same lethality results are output subsequently.

5. BRL-CAD raytrace against the correct target locations. The fragment velocity direction vectors must be properly handled within the code to ensure that the raytrace is performed against the correct target man geometries within the MOUT room.

6. Computerman and ORCA correct entry and exit locations and expected lethality results. Following from raytracing, it is important that 3DPIMMS produces the correct entry and exit points on the Computerman and ORCA target geometry models. This will be verified by comparing to the results of using the standalone versions of both Computerman and ORCA with the results from 3DPIMMS.

D. Face Validation

This is the process of determining whether models and simulations, on the surface, seem reasonable to persons who are knowledgeable about the particular system or phenomena. This method applies the knowledge and understanding of subject matter experts in the field and is subject to their individual biases. Face validation will be considered throughout all V&V analysis.

E. Comparisons to Other Models

This uses results or output from internal algorithms or M&S already accredited for use in similar applications as part of both structural and output validation. These comparisons have the limitation that the resulting degree of real-world fidelity is only as good as that of the M&S with which it is being compared. Although not the real world, it may be the best that is reasonably available for comparison. [4] There are other tools related to 3DPIMMS and based on its architecture that are currently in use within the vulnerability/lethality/survivability community. Many of these later tools utilize the same underlying injury models included in 3DPIMMS, and as such, can provide suitable data for its V&V. These tools include the Advanced Joint Effectiveness Model (AJEM) and Integrated Casualty Estimation Methodology (ICEM). Analyses will be performed using these different tools and results will be compared with 3DPIMMS analysis for certain scenarios.

F. Graphics and Visualization

Animation, graphics, and visualization techniques allow for the analyst to observe the M&S' behavior through time. This is particularly valuable when validation representations of a weapon functioning and its target interaction [4]. 3DPIMMS incorporates several graphical tools used to display data inputs, outputs, and analysis. These tools will be used extensively throughout the V&V process.

G. Acceptability Criteria

This section will address the criteria that 3DPIMMS must meet to determine if it is suitable for its intended use. According to DA PAM 5-11 [4], failure of a model or simulation in achieving a particular acceptability criterion does not automatically result in the model or simulation not being accredited. Such an occurrence may result in an evaluation of the criticality of the criterion to overall success and merely serve to restrict the range of applicability of the problem. The following criteria will be used to determine the acceptability of 3DPIMMS in the analytical community as an evaluation tool:

- 3DPIMMS is suitable for determining the effectiveness of munitions against personnel within MOUT structures.
- The definition of incapacitation used in 3DPIMMS is sufficient for assessing the degradation level of personnel located within MOUT structures.
- The output of 3DPIMMS, both quantitative and graphical, may be used clearly, adequately, and appropriately to address how well a munition performs against personnel within MOUT structures.
- Required data values are well defined, and the sources for obtaining data have been identified.
- The algorithms, methodology, and environment representations are functionally adequate to address the scenarios being analyzed.
- Similar methodologies used in the vulnerability/lethality/survivability community produce similar results to analysis performed with 3DPIMMS.

IV. ACCREDITATION AGENCY

The agency responsible for accreditation of Army models and simulations is ATEC.

V. PLANNED TIMELINE

The 3DPIMMS V&V will be performed and reported in a sufficient timeframe that will support anticipated program needs of Hellfire R, Joint Air-to-Ground Missile (JAGM), and Javelin as well as other future weapon systems.

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LIST OF ACRONYMS AND ABBREVIATIONS

3DPIMMS	Three-Dimensional Probability of Incapacitation Methodology for Masonry Structures
AEC	Army Evaluation Center
AJEM	Advanced Joint Effectiveness Model
AMRDEC	Aviation and Missile Research, Development, and Engineering Command
AMSAA	Army Materiel Systems Analysis Activity
ARL	Army Research Laboratory
ATEC	U.S. Army Test and Evaluation Command
ATO	Army Technology Objective
BD	Ballistic Dose
BDM	Bunker Defeat Munition
BRL	Ballistics Research Laboratory
BRL-CAD	Ballistics Research Laboratory Computer Aided Drafting
CKEM	Compact Kinetic Energy Missile
CSC	Computer Sciences Corporation
ICEM	Integrated Casualty Estimation Methodology
JAGM	Joint Air-to-Ground Missile
JCM	Joint Common Missile
JMEM	Joint Munitions Effectiveness Manual
JTCG/ME	Joint Technical Coordinating Group for Munition Effectiveness
MOUT	Military Operations in Urban Terrain
MPIM	Multi-Purpose Individual Munition
MRM	Mid-Range Munition
ORCA	Operational Requirement-Based Casualty Assessment
PGMM	Precision Guided Mortar Munition
S&T	Science and Technology
SK	Sperazza-Kokinakis
SSDD	System Simulation and Development Directorate
TOW	Tube-Launched Optically-Tracked Wire-Guided
UAH	University of Alabama in Huntsville
V&V	Verification & Validation

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