A COMPUTER PROGRAM FOR PREDICTING AND MAPPING BLAST EFFECTS AT ORDNANCE REMEDIATION SITES

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ABSTRACT

The U.S. Army Engineering and Support Center, Huntsville, is the Army's Mandatory Center of Expertise and Design Center for ordnance and explosives remediation. In this role, the Center is the execution agency for removal of unexploded ordnance from active military installations, installations slated for closure, and formerly used defense sites. Ordnance cleanup operations clearly include the risk of explosions, and the attendant fragment and overpressure hazards. Planning for these projects includes taking the appropriate steps to predict these effects and protect nearby people and their property. Most of this planning is done in the engineering and safety offices. However, sometimes ordnance and explosives (OE) items not included in the plan are discovered. Also, in the preliminary phases of a site investigation, the exact ordnance on the site and its possible locations may not be known. In these instances, a quick, reliable tool is needed for predicting blast effects in the field, at the site.

The Huntsville Center and the U.S. Army Construction Engineering and Research Laboratory have developed a software system called Mapping Explosive Safety Hazards, or MESH. This system performs prediction of blast effects for preliminary site safety planning at OE remediation sites, both in the design office and in the field. MESH is a "miniature" Geographical Information System (GIS). It determines expected blast effects and displays hazard arcs on a map of the specific site. The program uses accepted methods of predicting blast overpressure, fragmentation, and chemical agent dispersal, by incorporating existing, generally approved software. It also takes into account the effect of burial of the munitions. The program uses Intergraph's Microstation software as the main graphics driver, and will be incorporated into the Center's OE GIS and Knowledge Base system. The site map can be either an Intergraph map file or a map from commercially available mapping software. MESH provides the ability to make conservative, preliminary predictions of blast effects on the site.

This paper presents the development and capabilities of the MESH system for predicting and displaying blast effects. Integration of existing software, to predict blast effects, is outlined. New programming for buried explosion effects is discussed. The program and its use are demonstrated. Potential uses of this program, both on OE sites and in other applications, are presented.

INTRODUCTION

The U.S. Army Engineering and Support Center, Huntsville, is the U.S. Army Corps of Engineers Mandatory Center of Expertise and Design Center for Ordnance and Explosives (OE MCX). In this role, the Huntsville Center both sets Army policy for remediation of unexploded ordnance (UXO), and executes OE remediation projects at many sites. These projects include formerly used defense sites, active installation restoration, and sites being prepared for Base Realignment and Closure.

An important part of planning and executing UXO remediation is, obviously, ensuring the safety of the workforce and the public. This involves evaluating the ordnance on the sites; determining the hazards, including blast pressures, primary fragmentation and chemical agents; and developing any necessary engineering controls to provide the appropriate level of protection. This has been predominantly an engineering function, performed by safety specialists and designers in the engineering office rather than at the remediation site. It requires a relatively high level of expertise in blast effects and methods of mitigation. Some computer programs exist to assist the designer in performing this analysis. However, these programs are single point solutions. That is, each program can examine one facet of an explosive

safety problem. However, they require the designer to have significant expertise in explosive safety. Also, these programs are not integrated into a single software system, which requires the designer or safety professional to run several programs, usually in a time-consuming, iterative process.

Based on these limitations, the OE MCX identified the need to be able to perform simple safety analyses at the site. Ideally, such an analysis could be performed by an integrated software solution that combined the point solution software into one system. Also, such a system should include an easily understandable, graphical display of results. The Huntsville Center, in partnership with the Corps' Construction Engineering and Research Laboratory, has developed such a system, called Mapping Explosive Safety Hazards, or MESH. This paper presents the basic system architecture and capabilities of the MESH program.

MESH PROGRAM CAPABILITIES

MESH is an integrated software system that predicts blast effects from conventional and chemical ordnance and displays hazard distances on a site map. MESH is essentially a simple geographical information system (GIS). Both the input to the analysis software and the output are integrated with and displayed on a computerized map of the OE site. MESH predicts blast effects using either existing software, or new programs that use accepted and approved methodologies. Blast effects that MESH can predict include blast overpressures, primary fragments, and chemical agent dispersion. Also, MESH can model the reduction of fragment hazards due to buried explosions. Input from the user includes the types and locations of ordnance on the site and specification of the desired blast effects. MESH outputs include a graphical display of hazard distances on the site map. This display permits the user to easily identify possible threats to personnel and property, and determine where engineering controls may be required.

MESH SYSTEM ARCHITECTURE

MESH uses the Microstation computer graphics program, developed by Bentley Systems, Inc., and marketed by Bentley and Intergraph Corporation, as the main graphical user interface. While experience in using Microstation is helpful, the typical MESH user will need to know only a few simple Microstation commands in order to view the results. MESH is written as a series of blast effects program modules linked together by a shell written in Microstation Development Language (MDL). This MDL shell collects data from the user, executes the individual modules, and plots the results. MESH is designed to run on either a desktop or portable, notebook personal computer.

Data is input by the user on a series of input cards, which are small windows that overlay on the site map. These include an introductory card, a general program control card, two card for selecting donor munitions, one card for each analysis module, and one card for output control and program execution. The user may input data in any order, but the cards are arranged in the most logical sequence for the analysis to be performed. The user navigates through the cards by using a mouse to press on-screen buttons or access menus. Specific input on each card is done with the mouse and some keyboard entries. Each card also includes context-specific, on-line help. From any card, the user can simply request help by clicking on the help icon. MESH will then open a help card specific to that input card, with complete instructions on how to execute each option and in which order. The user can use the Microstation graphics capabilities to zoom, pan, and otherwise navigate through the site map in order to set up the problem and examine results. After any analysis, the user can easily make changes to the input and run the analysis again.

BASIC STEPS IN MESH OPERATION

The basic sequence of steps to run MESH is as follows:

- Select a map of the site to be evaluated. This map can be either a Microstation GIS site map or a simple street map developed from CD-ROM based map software. MESH establishes a connection between the site map and the data set to be analyzed.
- Input the types and locations of ordnance items.
- Provide specific input for each analysis module.
- Execute the explosive effects analysis.

IDENTIFYING DONOR ORDNANCE

After selecting and displaying the site map, the user defines a series of donor positions, which are locations on the map at which ordnance items are located or anticipated. The Donor Ordnance Position card is shown in Figure 1. From this card, the user can add new donors, and edit or delete existing donors. When adding or editing donor positions, the user selects items from a Munitions Database shown on the Add/Edit Munitions card (Figure 2). Each donor position can have any number of ordnance items, and any combination of ordnance types. So, for example, the user can select one

81-mm mortar round, three of these rounds, or a combination of 81-mm and 75-mm rounds, for a single donor position. The user can also add a bare explosive charge to the donor, as an initiating charge in open detonation, or use a bare charge alone. After identifying the donor rounds, the user sets the location by simply clicking on the proper location on the site map.

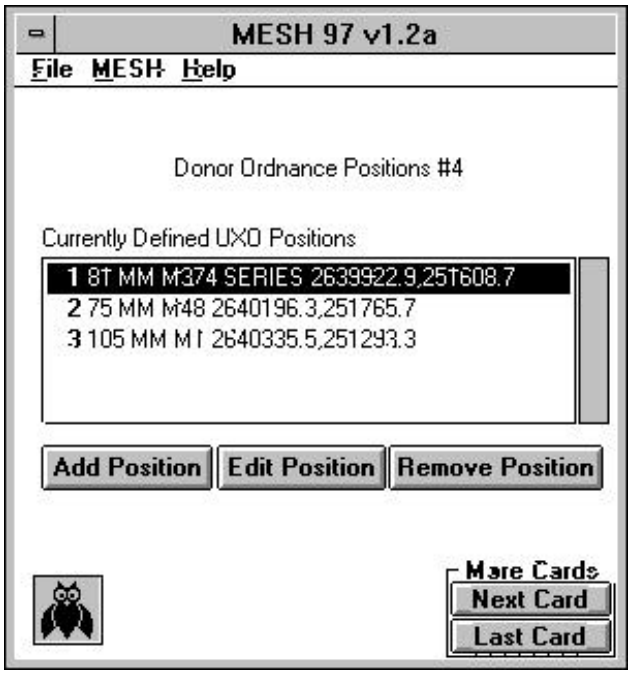

Figure 1. Donor Ordnance Position Card

The Munitions Database contains information on a number of typical ordnance items. The database includes the name of the item, explosive charge weight in equivalent pounds of TNT, critical fragment weight and velocity, and the type and weight of any chemical agent in the munition. The items currently in the database include:

- 20-mm M56A4 Cartridge
- 37-mm MK II Projectile
- MK 2 HE Hand Grenade
- 40-mm MK 2 Projectile
- 60-mm M49A3 Mortar
- 75-mm M48 Projectile
- 81-mm M374 Mortar
- 105-mm M1 Projectile
- 155-mm M107 Shell
- 4.2-inch M3A1
- 3-inch and 4-inch Stokes Mortar
- 2.75-inch M229 Rocket
- 2.36-inch M6A3 Rocket
- 8-inch M106 Projectile
- 4.7-inch Mark I Projectile
- 500-lb M64A1 Bomb
- 2,000-lb M66A1 Bomb
- 12,000-lb T10 Bomb

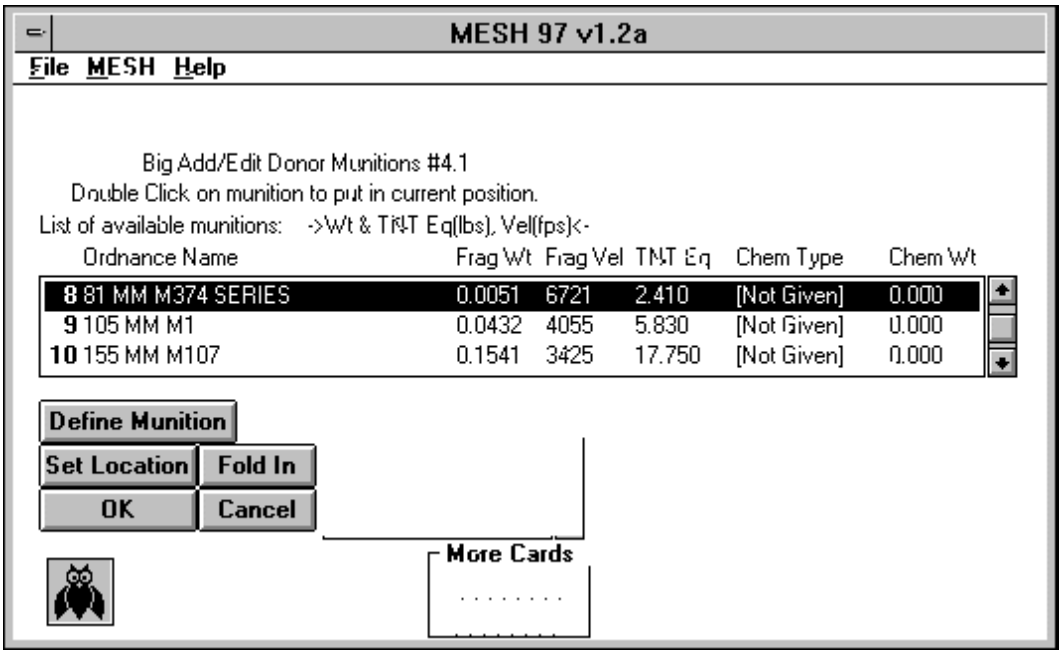

Figure 2. Add/Edit Donor Munitions Card

Other munitions will be added to the database as needed. The user may select any of these munitions or create a new item that is not in the database. However, any user-defined item must include the explosive charge weight expressed in equivalent pounds of TNT, plus the design fragment weight and velocity and any chemical agent information. Ideally, actual fragmentation data should be included. There are accepted computational methods for making reasonably conservative predictions of fragment characteristics. These methods are not complex, but they generally require expertise in weapons effects to produce reasonable values. Therefore, the data for user-created munitions should be developed by someone with the appropriate experience.

OVERPRESSURE MODULE

The Overpressure Module uses the Kingery curve equations [1], which are approved equations for predicting blast pressures used in TM 5-1300 [2] and other references. The module computes overpressures based on a bare spherical charge, ignoring any reduction in the effective charge weight caused by the energy required to shatter the weapon case.

The Overpressure Module card is shown in Figure 3. The user chooses which overpressures are of interest by selecting from a list of standard explosive safety quantity distances (Q-Ds). Both standard U.S. and NATO Q-Ds are available. Each Q-D corresponds to a specific incident overpressure. These Q-Ds are defined relative to the cube root of the explosive charge weight. The U.S. distance is defined as

$$Z = KW^{1/3}$$

where Z is the Quantity Distance in feet, W is the explosive charge weight in pounds of TNT, and K is a factor based on the permissible overpressure exposure for a given acceptor (or target) type. NATO standard Q-Ds are defined, similarly, as

$$Z = KQ^{1/3}$$

where Z is the Q-D in meters and Q is the explosive mass in kilograms of TNT. U.S. and NATO standard K-factors and overpressures, that have been included in MESH, are listed in Table 1. The user may select one or all of these values. The user also has the option to specify other overpressure levels, in pounds per square inch (psi).

For each donor position, MESH computes the distances to all of the specified overpressure levels. MESH assumes that the total charge weight in each donor detonates simultaneously.

Since the distances are based on charge weights, they can vary for different donors. MESH plots the overpressure distances as a set of concentric contours centered on each donor location. Each contour can be labeled with the applicable K value, pressure, and distance.

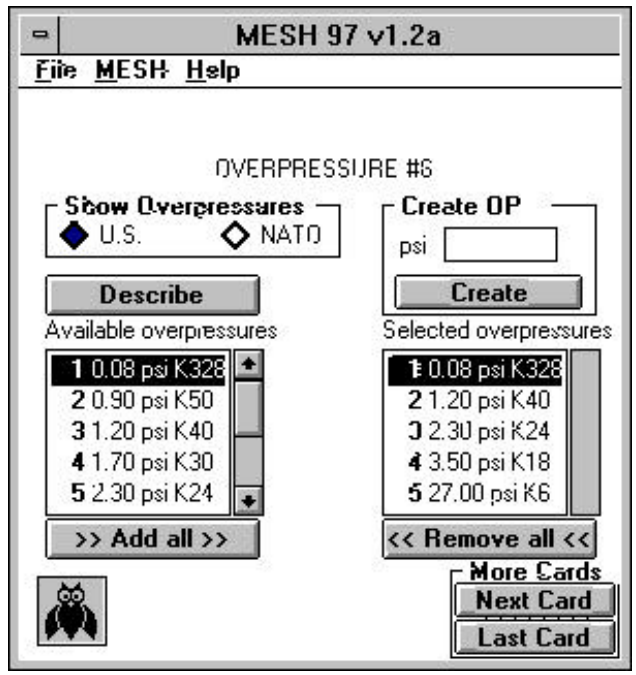

Figure 3. Overpressure Module Card

Table 1. Standard Overpressures and K-Values

Overpressure (psi)	U.S. K-value	NATO K-value
0.08	328	---
0.23	---	55.5
0.3	---	44.4
0.8	---	22.2
0.9	50	---
1.2	40	---
1.3	---	14.8
1.7	30	---
2.3	24	9.6
3.0	---	8
3.5	18	---
12.0	9	3.6
27.0	6	2.4

FRAGMENTATION MODULE

The Fragmentation Module is based on the computer program TRAJ [3], which calculates the flight trajectory, range, and impact energy for fragments. TRAJ normally requires a significant list of specific inputs, including fragment weight, velocity, material, shape characteristics, initial trajectory angles, and terrain data. However, most of this input has be programmed into MESH for typical, standard shaped fragments from cased munitions. Thus, the user need not have extensive experience in using TRAJ or analyzing the fragmentation characteristics of munitions.

MESH adds the critical fragment weight and velocity from the donor munitions, as given in the munitions database or by the user, to the normal TRAJ input. MESH then executes TRAJ for a series of launch angles, generally from 1 to 89 degrees from the horizontal. TRAJ computes the range and impact energy for each angle, storing this data in an output file. MESH scans this file and determines the maximum fragment range and the range to the farthest hazardous fragment. A hazardous fragment is defined as one with an impact energy of 58 foot-pounds (ft-lb). The DOD Ammunition and Explosive Safety Standards, DOD 6055.9-STD [4], limit personnel exposures to one hazardous fragment per 600 square feet of impact area. However, MESH cannot make statistical predictions of the areal density of fragment impacts. Therefore, MESH simply determines the farthest impact distance for 58 ft-lb fragments. This provides a conservative distance for determining exclusion zones.

The input card for fragmentation analysis is shown in Figure 4. User input for fragmentation analysis is quite limited. The user must simply check whether MESH should plot one or both of the two fragment distances. Upon completion of the analysis, MESH plots the selected fragment hazards distances as circular contours around each donor location. MESH also returns the distances to the Current Donor Locations list on the fragmentation card.

BURIED EXPLOSION MODULE

MESH includes the ability to evaluate the effect of burial, or earth tamping, on the primary fragments from a munition. This permits the user to evaluate the depth of burial that may be required for open detonation of an ordnance item. MESH computes the reduced effects using the Buried Explosion Module (BEM), which includes programming written by the Huntsville Center.

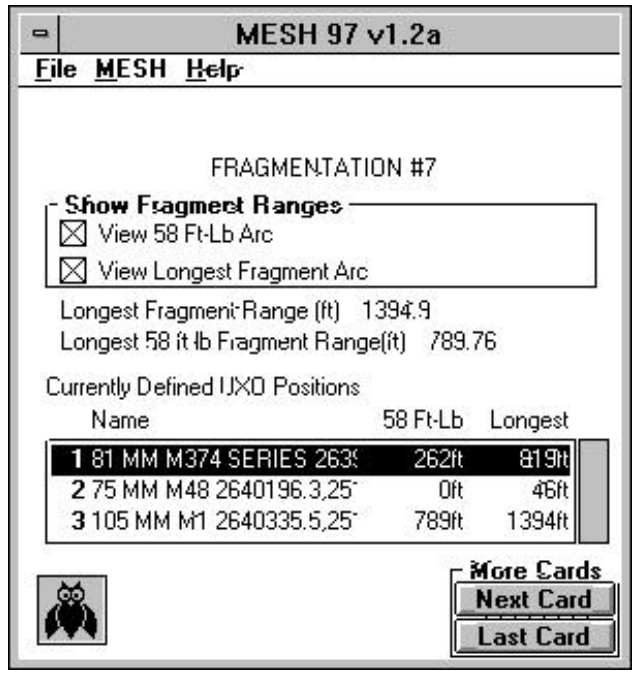

Figure 4. Fragmentation Module Card

The BEM uses a revised procedure approved by the DOD Explosives Safety Board (DDESB). Essentially, the BEM calculates the effective soil depth from the actual burial depth and the explosive charge weight. The effective soil depth is computed as the difference between the actual crater depth and apparent crater depth, using equations from TM 5-855-1 [5] and the computer program CONWEP [6]. If the effective soil depth is zero, MESH warns the user that burial to the specified actual depth will not reduce fragment distances. If the effective soil depth is positive, then the soil is treated as a disturbed medium through which the primary fragments must pass. The residual velocity, if any, is calculated, and passed to the Fragmentation Module, instead of the original fragment velocity. Also, the BEM computes the ejecta range for each donor location. This is the range that the explosion will throw soil particles.

The input card for buried explosions is shown in Figure 5. On this card, the user inputs the burial depth in feet and selects the applicable soil type. These parameters are input separately for each donor position. After executing the analysis, MESH plots the reduced fragment distances and ejecta range for each donor instead of the fragment ranges from a detonation on the surface. It also returns these reduced distances to the table on the Fragmentation Module card. At this writing, MESH does not predict the reduction in overpressures due to burial. This is being considered for future development in MESH.

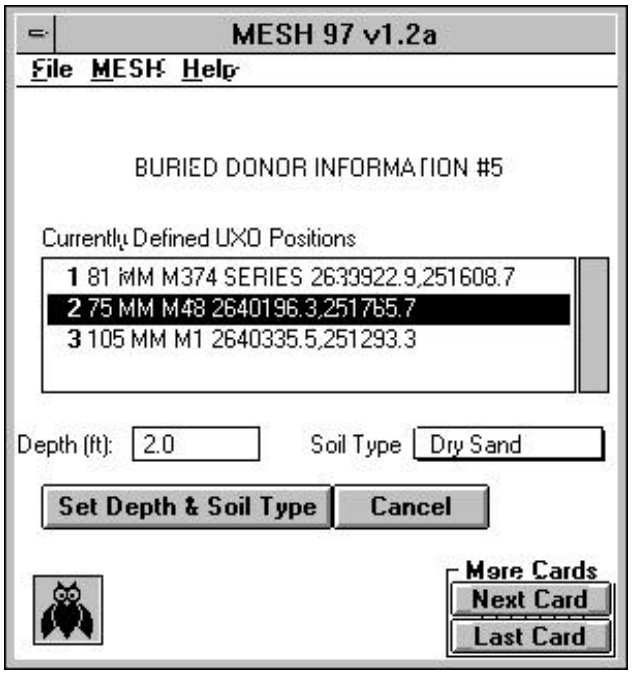

Figure 5. Buried Explosion Module Card

CHEMICAL AGENT MODULE

The Chemical Agent Module is based on the computer program D2PC [7]. This program predicts hazardous chemical agent dispersion ranges. These are the No Significant Effect (NOSE), 0% lethality and 1% lethality ranges. D2PC normally requires significant input about the site and meteorological conditions. In order to develop this input, the user normally would need a high level of expertise. However, most of the input to D2PC has been programmed into MESH.

The Chemical Agent Module input card is shown in Figure 6. On this card, the user selects which of the three chemical agent hazard distances are desired. The user also selects the air temperature, wind speed, and mixing depth. Each of these values is selected from a pop-out menu. The mixing depth or height can be selected as a height in feet, or by selecting one of three terrain types: flat, hilly, or mountainous terrain. These input parameters apply to the entire site; that is, they are used for all of the donor positions. Given these values and the pre-programmed input, MESH executes the D2PC program for donor positions that contain a chemical agent, obtaining the three hazard distances. These distances are then plotted on the site map for each donor position, and the numerical ranges are returned to the table on the Chemical Agent Module card.

It should be noted that, because of the pre-programmed input values, MESH computes chemical agent dispersal ranges that are approximate and should only be used as guidelines. However, since the pre-programmed input to D2PC includes certain assumption, the hazard distances may not be entirely applicable to the site being considered. At this writing, MESH should not be used to determine safety requirements for chemical weapons but, instead, should be used to identify potential problem areas for which a more detailed analysis using D2PC is required. Future development of MESH will address the issue of improving the accuracy and applicability of chemical agent hazard results. This may include a more complete integration of D2PC such that all input parameters can be entered by the user.

Figure 6. Chemical Agent Module Card

PROGRAM EXECUTION

Once all pertinent data has been entered on the input cards, the user may execute the analysis from the Main Output Control Card (Figure 7). This card allows the user to select which of the blast effects hazards to display on the screen. MESH will compute all of the hazard distances on every run. The user simply has the option of turning off the overpressure, fragmentation and chemical agent contours. This can be useful for a site analysis with a large number of donors. Also, this card lets the user specify whether to plot curve labels and distances. These selections can be made before or after the analysis

is performed. Execution of the analysis programs is initiated by clicking on the Run Analysis button.

A typical MESH screen after the analysis has been executed, with overpressure and fragment contours, is shown in Figure 8. This example includes three donor positions. Position one contains one M374 series 81-mm Mortar. Position 2 contains one 75-mm M48 Projectile, and Position 3 includes one 105-mm M1 Projectile. The M48 at Position 2 is buried under 2 feet of dry sand; the other items are on the surface. The background site map is the parade ground at Ft. Monroe, VA. For each donor, overpressure contours are shown for 1.2, 2.3, 3.5 and 27.0 psi. Fragmentation distances were also plotted for each donor, but for clarity, the view in Figure 8 is zoomed in to show mainly the overpressure contours. The MESH Main Output Control card is in the lower right corner. The typical Microstation command box and main palette are in the upper left corner. This plot clearly shows that overpressures from Positions 1 and 2 pose little threat to surrounding buildings. Donor Position 3, located between two buildings, will cause overpressure hazards to the inhabitants of those buildings. Also, the ordnance at Positions 1 and 3 will throw primary fragments over a considerable distance, nearly 1,400 feet from Position 3. However, MESH predicts that the sand cover over Position 2 will reduce the maximum fragment range to only 46 feet, with a predicted ejecta range of 127 feet.

Figure 7. Main Output Control Card

ADDITIONAL FEATURES

MESH includes a number of additional features designed to assist the user. Each MESH card has a companion card that provides context-specific, on-line help. Each help card describes the functions available on each card, and the appropriate sequence of keystrokes and mouse clicks needed to execute these functions. The help card can be accessed automatically from any MESH input card by clicking on the owl icon. The input card and help card are both visible on the screen, so the user can refer to the help card while actually entering data. Also, the user may scroll through the help cards separately from the MESH input cards at any time.

MESH is designed to plot hazard distance contours over a digital site map. However, such a map may not always be available for every site. For example, in an emergency response situation, ordnance may be discovered in an area for which no digital maps are available. To provide for this, MESH includes the capability to use a raster file street map instead of a digital site map. This street map can be recovered from a CD-ROM based map program. A procedure is provided for capturing such a map and loading it into a site map file.

The complete installation of MESH also includes two on-line movies, viewable through Microstation. One movie provides a demonstration how to use MESH, including instructions for every card. The other movie illustrates the method of capturing a raster map file from a commercial CD-ROM based mapping program.

SYSTEM REQUIREMENTS

MESH is designed to be run on a desktop or notebook, IBM-compatible personal computer, running Windows, Windows NT or Windows 95, with at least 16 megabytes (MB) of memory. Basic installation of MESH requires 5.4 MB of hard disk space; complete installation with movies requires 18.6 MB. The computer must have Microstation on board or accessed via a network. In order to use the CD-ROM based site maps, a CD reader is required.

POTENTIAL USES OF MESH

Clearly, MESH can be used in safety planning for ordnance remediation projects. MESH can provide the engineering use with the ability to evaluate potential hazards to the public, evaluate blast effects, and design adequate engineering controls. The system can also be easily used by the safety professional at the remediation site, for both planning and ongoing evaluation of safety

Figure 8. Typical MESH System Screen View

during project execution. Additionally, MESH is expected to have immediate application in site safety planning for any site. MESH predicts blast and primary fragment hazards using approved methods, and can do so for any explosive hazard. The graphical presentation of this information will be of value for general explosive safety applications, both now and as future developments are implemented.

FUTURE DEVELOPMENT

A number of additions and enhancements to MESH are planned or being contemplated. MESH will be integrated into the Huntsville Center's Ordnance and Explosives Knowledge Base (OE-KB). This is a complete GIS designed for use in planning and executing OE remediation projects, including a number of analysis tools. MESH will be incorporated to become an additional analysis engine to be used in the GIS. A stand-alone version of MESH will be retained for use on notebook computers in remote sites, and by users who do not need the complete OE KB functionality.

A reporting module will be added to MESH to produce a text summary of MESH inputs and output results. A customized Microstation MESH workspace will be developed. This workspace will essentially define the environment in which MESH is used in Microstation, and provide easier access to graphics functions for users who have limited Microstation experience. The workspace will also include customizable display options, to provide the more sophisticated user the ability to change how MESH looks on the screen.

Better prediction of weapons effects will be implemented into MESH. This may include linking MESH to a similar program called ERASDAC, the Explosion Risk and Structural Damage Assessment Code [8], developed

separately by Huntsville Center for the DOD Explosives Safety Board. ERASDAC has the capability to predict damage to structures from blast pressures. Therefore, a link to ERASDAC would permit the MESH user to predict not only weapons effects, but the results of these effects on military and civilian facilities. A more detailed integration of D2PC into MESH is being considered. As stated above, this may include a direct link to D2PC, to permit the experienced user to perform more detailed chemical agent analysis and produce more accurate results. Also, work is being performed to improve the Buried Explosion Module based on actual test data. As the BEM is improved, the pertinent data will be included in MESH.

Huntsville Center has developed a set of standard barricades for reduction of fragmentation hazards from ordnance and a guide to the selection and use of these barricades [9]. The barricade guide is discussed in detail in another paper in these proceedings [10]. We are considering automating the barricade guide and incorporating it into MESH. This will permit designers and planners to evaluate different barricade designs and locations for reduction of fragmentation hazards.

CONCLUSIONS

MESH provides engineering and safety professionals with a fast, easy-to-use method of predicting weapons effects at OE remediation sites. Its predictions of blast overpressures and primary fragment ranges are computationally accurate. Predictions of chemical agent hazards are generally correct, although some refinement is needed before these can be used as absolutes for safety planning. A number of future developments have been identified that will increase the value of MESH to the ordnance and explosive safety community. MESH is expected to be used widely on OE remediation projects, which will provide a basis for even further refinements to the system. At this writing, version 1.2 of MESH is complete and available for use in OE safety site planning.

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