

# **ASSESSMENT OF SECONDARY FRAGMENT THREATS FROM CONVENTIONAL DOD BUILDING CONSTRUCTION**

BY

**James P. Manthey**

Corps of Engineers, Huntsville Division  
106 Wynn Drive; Huntsville, Alabama 35805-1957

## **ABSTRACT**

Army installations have to begin to make more efficient use of property. The default DoD 6055.9 minimum inhabited building separation distances required for secondary fragments are often excessive and they are difficult and costly to meet. In order to reduce the separation distance it is required to determine, using approved methods, the separation distance providing a fragment density of less than 1 hazardous fragment per 600 square feet. Until recently a standard approved method was not available. A procedure was developed by Southwest Research Institute for the Department of Energy (DOE) and the Department of Defense Explosive Safety Board (DDESB). This procedure was approved for use by DDESB and is described in Technical Paper No. 13 (TP 13), "Prediction of Building Debris for Quantity-Distance Siting". However, this method is complex and requires experience in fragment analysis and the use of three explosive analysis computer programs. This paper summarizes a study by Huntsville Division, U.S. Army Corps of Engineers for DDESB on a simplification of procedures in TP 13 for typical Army construction types. The procedure is intended for personnel with limited fragment analyses experience.

## **BACKGROUND**

The Army explosive safety and processing community requires easy to use, quick, accurate tools to assess safety hazards resulting from explosions. In the past, Army installations had ample property and could ensure personnel and public safety by providing large separation distances between inhabited buildings and explosive processing and storage facilities. Formerly remote Army installations are now often surrounded by inhabited private property. Efficient use of available property is required and desired while maintaining personnel safety. The recent events in Henderson, Nevada have illustrated that neglecting safety is costly in both lives and money. It is therefore necessary that a more accurate and relative determination of threats to personnel

| Report Documentation Page                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |                                    |                                     |                                                                  | Form Approved<br>OMB No. 0704-0188                  |                                    |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------|-------------------------------------|------------------------------------------------------------------|-----------------------------------------------------|------------------------------------|
| Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number. |                                    |                                     |                                                                  |                                                     |                                    |
| 1. REPORT DATE<br><b>AUG 1992</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |                                    | 2. REPORT TYPE                      |                                                                  | 3. DATES COVERED<br><b>00-00-1992 to 00-00-1992</b> |                                    |
| 4. TITLE AND SUBTITLE<br><b>Assessment of Secondary Fragment Threats from Conventional DoD Building Construction</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |                                    |                                     |                                                                  | 5a. CONTRACT NUMBER                                 |                                    |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |                                    |                                     |                                                                  | 5b. GRANT NUMBER                                    |                                    |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |                                    |                                     |                                                                  | 5c. PROGRAM ELEMENT NUMBER                          |                                    |
| 6. AUTHOR(S)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |                                    |                                     |                                                                  | 5d. PROJECT NUMBER                                  |                                    |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |                                    |                                     |                                                                  | 5e. TASK NUMBER                                     |                                    |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |                                    |                                     |                                                                  | 5f. WORK UNIT NUMBER                                |                                    |
| 7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)<br><b>U.S. Army Corps of Engineers,Huntsville Division,106 Wynn Drive,Huntsville,AL,35805-1957</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |                                    |                                     |                                                                  | 8. PERFORMING ORGANIZATION<br>REPORT NUMBER         |                                    |
| 9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |                                    |                                     |                                                                  | 10. SPONSOR/MONITOR'S ACRONYM(S)                    |                                    |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |                                    |                                     |                                                                  | 11. SPONSOR/MONITOR'S REPORT<br>NUMBER(S)           |                                    |
| 12. DISTRIBUTION/AVAILABILITY STATEMENT<br><b>Approved for public release; distribution unlimited</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |                                    |                                     |                                                                  |                                                     |                                    |
| 13. SUPPLEMENTARY NOTES<br><b>See also ADA260986, Volume III. Minutes of the Twenty-Fifth Explosives Safety Seminar Held in Anaheim, CA on 18-20 August 1992.</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |                                    |                                     |                                                                  |                                                     |                                    |
| 14. ABSTRACT<br><b>see report</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |                                    |                                     |                                                                  |                                                     |                                    |
| 15. SUBJECT TERMS                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |                                    |                                     |                                                                  |                                                     |                                    |
| 16. SECURITY CLASSIFICATION OF:                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |                                    |                                     | 17. LIMITATION OF<br>ABSTRACT<br><b>Same as<br/>Report (SAR)</b> | 18. NUMBER<br>OF PAGES<br><b>14</b>                 | 19a. NAME OF<br>RESPONSIBLE PERSON |
| a. REPORT<br><b>unclassified</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       | b. ABSTRACT<br><b>unclassified</b> | c. THIS PAGE<br><b>unclassified</b> |                                                                  |                                                     |                                    |

safety from accidental explosions be used.

There has been accepted methodology established for determination of the hazards posed by overpressure and primary fragments. There was not a consistently accepted methodology for analyzing the secondary fragment threats resulting from the breakup of the structural elements of facilities in an explosion.

Department of Defense (DoD) 'Ammunition and Explosives Safety Standards', DoD 6055.9-STD, (Reference 1) establishes uniform safety standards applicable to ammunition and explosives. Reference 1 states that "For populous locations ... where military, civilian employees, dependent and/or public personnel are located, the minimum distance (from the explosion source) shall be that distance at which fragments, including debris from structural elements of the facility or process equipment, shall not exceed a hazardous fragment density of one hazardous fragment per 600 square feet." Reference 1 defines a hazardous fragment as one having an impact energy of 58 ft-lb or greater. If this distance is not known, Reference 1 states "For 100 lbs NEW (net equivalent weight) or less of demolition explosives, thin-cased or low fragmentation ammunition items, bulk high explosives, pyrotechnics, and in-process explosives of Class/Division 1.1, the minimum distance ... shall be 670 ft." . Reference 1 further states that "For all types of Class/Division 1.1 in quantities of 101 to 30,000 lbs NEW, the minimum distance shall be 1250 ft ...".

The default minimum inhabited building separation distance for secondary fragments (IBD-F) required by Reference 1 are often overly conservative for structural debris. To avoid using the default IBD-F the hazardous fragment distance corresponding to 1 hazardous fragment per 600 square feet (HFD) must be determined. Historically, explosive safety personnel were given little guidance in determining the HFD. Thus, methods varied substantially. In order to provide consistency in analysis, the Department of Defense Explosive Safety Board (DDESB) issued Technical Paper No.13, 'Prediction of Building Debris for Quantity-Distance Siting', (Reference 2). Reference 2 provides an analytical model for determining the hazardous fragment density resulting from building debris. The model was developed by Southwest Research Institute (SwRI) for the Department of Energy (DOE) Safety Office under funding by DOE and DDESB for some common construction types. The model was refined and verified based upon data from testing by SwRI for DOE.

#### **TECHNICAL PAPER NO.13 ANALYTICAL MODEL**

Reference 1 provides a methodology with which to determine the hazardous fragment density resulting from building debris. The method involves the use of the three computer programs in

addition to hand calculations. The computer programs SHOCK and FRANG, developed by the Navy Civil Engineering Laboratory (NCEL), are used, respectively, to determine the explosive shock and gas pressures on the structural elements. The computer code MUDEMIMP, developed by NCEL and refined by SwRI to reflect test data, is then used to estimate the hazardous fragment density. MUDEMIMP requires as input the average mass based upon construction type, average velocity calculated using the loadings from SHOCK and FRANG, and initial trajectory of the building debris along with appropriate statistical distribution parameters. Through use of a monte-carlo randomization computer routine and statistics, MUDEMIMP determines trajectory distances for up to 5000 individual fragment weights, velocities, and initial trajectories and predicts a conservative estimate of the debris density.

The fragments are always assumed to eject normal to the surface of the structural element being considered with a standard deviation of between 1.3 and 10 degrees. The horizontal fragment dispersion used by MUDEMIMP is as shown in Figure 1 (from Reference 2). GRIDL is the effective destroyed wall width. MUDEMIMP bases its determination of hazardous fragment densities on an effective destroyed weight of structural element. The number and weight of fragments considered are also based on this effective destroyed weight. Only debris with an impact energy of greater than 58 ft-lbs are considered. MUDEMIMP predicts roll based upon the fragment impact velocity for the fragments with impact angles under 50 degrees. Fragments that have impact angles over 50 degrees are not assumed to roll.

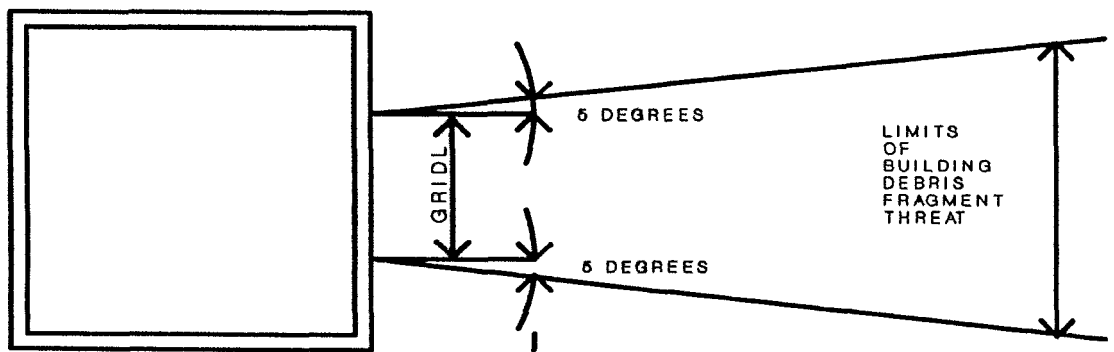
MUDEMIMP produces two output files. 'MIMP.OUT' provides all pertinent information on each of up to 5000 fragment trajectory simulations. 'MIMP.HIS' gives the maximum hazardous fragment distance (MFD) and the critical distance for cumulative risk (HFD). Mimp.his also provides hazardous fragment density (number of fragments per 600 sf) at successive distances from the surface.

This model, while extremely valuable to explosive safety specialists, requires experience in fragment analysis and in the use of the three computer programs. Safety personnel who do not regularly use this analytical model will find it time consuming, frustrating and costly to use. It is therefore desirable to have a simplified procedure for use on common Army building types.

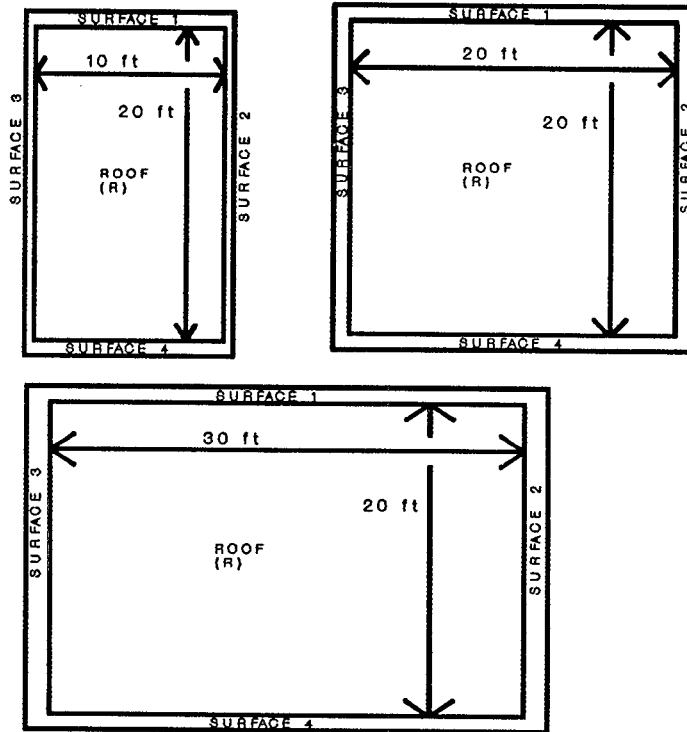
### **Army Building Debris Study**

The purpose of the study by the Corps of Engineers, Huntsville Division, is to provide a simple tool based upon Reference 2 to estimate the hazardous fragment density resulting from structural debris for typical U.S. Army building

## BUILDING DEBRIS LIMITS



**FIGURE 1 - MUDEMIMP BUILDING DEBRIS LIMITS**



| CONSTRUCTION TYPE |                                                                                                            |                     |
|-------------------|------------------------------------------------------------------------------------------------------------|---------------------|
| ABRV.             | DESCRIPTION                                                                                                | FOR USE ON SURFACES |
| CSF               | CORRUGATED STEEL PANELS<br>SUPPORTED ON STEEL CHANNELS<br>WITH 1" INSULATION<br>AND 5 PLY FELT AND GRAVEL. | ROOF                |
| CSF               | CORRUGATED STEEL PANELS<br>SUPPORTED ON STEEL CHANNELS                                                     | 1 AND 2             |
| RC                | 12" THICK REINFORCED CONCRETE<br>WITH #4 BARS @ 12" SPACING<br>IN EACH DIRECTION ON EACH FACE              | 1,2,3, AND 4        |
| CMU               | 8" STANDARD CONCRETE<br>MASONRY UNIT                                                                       | 1,2,3, AND 4        |
| SB                | 8"x12" STRUCTURAL BRICK                                                                                    | 1,2,3, AND 4        |

**FIGURE 2 - STUDY PARAMETERS**

construction types. The main objective is to provide a method which would require little or no knowledge of the procedures described in reference 2. Therefore, a graphical procedure is being developed based upon the use of a set of graphs depicting hazardous fragment density versus distance for typical construction materials, bay sizes, and venting conditions. The use of the procedure will be described later in this paper.

The study parameters including bay sizes, construction materials, and venting surfaces are shown in Figure 2. Three bay sizes with surfaces 1 and 2 as possible vent surfaces and the roof always as a covered venting surface are considered. The four construction materials considered are as follows:

- 1 20 gage corrugated metal deck frangible surface (with 1" rigid insulation and 5 ply felt and gravel on roof) supported on structural steel channels (CSF)
- 2 12" thick concrete reinforced with #4 bars at 12" spacing each way on each face (RC)
- 3 unreinforced 8" standard concrete masonry unit (CMU)
- 4 8"x12" unreinforced structural brick (SB)

The three bay dimensions are as follows:

- 1 20' long by 10' wide by 20' high
- 2 20' long by 20' wide by 20' high
- 3 20' long by 30' wide by 20' high

Fragment analyses based upon Reference 2 will be performed for each bay size, venting condition, and material type for net equivalent explosive weights of 25, 50, and 100 pounds.

The product provided from this study will be a set of 62 graphs of the expected hazardous debris density versus distance from the structural element, the maximum hazardous fragment range (MFD), the maximum critical distance for cumulative risk (HFD), and the zero hazardous fragment density distance (ZFD). A sample graph as will be presented in the final study report is shown in Figure 3.

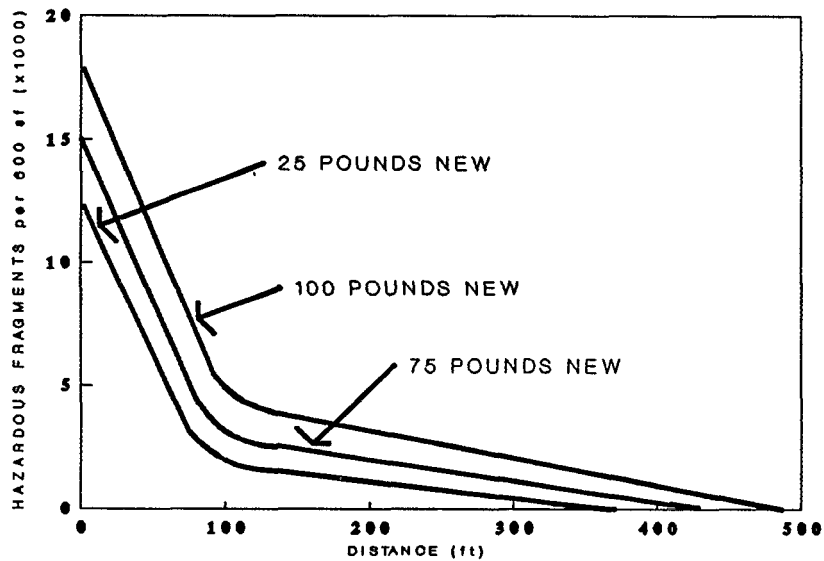
#### EXAMPLE

As an example to illustrate how the information provided within the study can be used, a situation as shown in Figure 4 is

# ARMY BUILDING DEBRIS STUDY

## GRAPH 34

**FOR EXAMPLE ONLY**



### 25 POUNDS NEW

MAXIMUM PREDICTED DISTANCE = 360 ft

MAXIMUM PREDICTED CRITICAL DISTANCE FOR CUMULATIVE RISK (HFD) = 345 ft

ZERO HAZARDOUS FRAGMENT DENSITY DISTANCE = 370 ft

### 50 POUNDS NEW

MAXIMUM PREDICTED DISTANCE = 430 ft

MAXIMUM PREDICTED CRITICAL DISTANCE FOR CUMULATIVE RISK (HFD) = 415 ft

ZERO HAZARDOUS FRAGMENT DENSITY DISTANCE = 440 ft

### 100 POUNDS NEW

MAXIMUM PREDICTED DISTANCE = 480 ft

MAXIMUM PREDICTED CRITICAL DISTANCE FOR CUMULATIVE RISK (HFD) = 465 ft

ZERO HAZARDOUS FRAGMENT DENSITY DISTANCE = 490 ft

**FIGURE 3 - SAMPLE STUDY GRAPH (NOT FOR USE - EXAMPLE)**

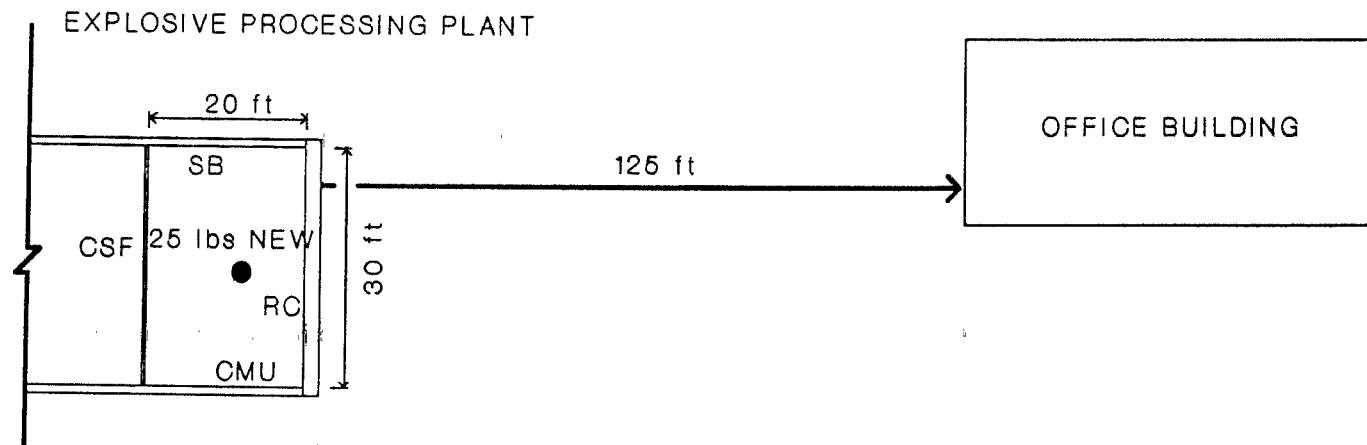


FIGURE 4 - EXAMPLE CONFIGURATION

considered. There is a explosive processing plant with an end bay having a 12" concrete thick back wall, masonry side walls and frangible metal deck front wall and roof. The end bay has interior dimensions of 30 feet wide by 20 feet long by 20 feet high. There is 25 pounds net equivalent weight of explosive in the end bay. An office building is located 125 feet from plant. The default IBD-F required by Reference 1 is 670 feet. The hazard to personnel in the office building resulting from an accidental explosion in the plant's end bay must be determined.

The first step is to determine which surfaces contribute to the secondary fragmentation hazard at the office building. Figure 5 shows the limits of fragment scatter for each surface. It can be seen that only building debris from the concrete back wall and the metal roof deck need be considered for determining the hazardous fragment density at the office building. From figure 2, it is noted that the back concrete wall of the end bay corresponds to surface 4.

The next step is to select the graphs which will be used in determining the aggregate fragment hazard. The graph selection chart (Figure 6) is used to determine which graphs are to be used for the situation in question. Therefore, graph 27 (Figure 7) for the back wall (surface 4) and graph 29 (Figure 8) for the roof (surface R) are selected for venting through surfaces 1 and roof and a bay size of 20 ft by 30 ft by 20 ft.

With the appropriate graphs selected, the values of MFD, HFD, and ZFD should be looked at for both surfaces. If the siting distance is less than either of the two surface's HFD values, the siting does not meet the requirements of Reference 1 since the hazardous fragment density will exceed 1 fragment per 600 square feet. Figure 8 states that the MFD for the roof fragments is 144.2 feet, the HFD is 57.96 feet, and the ZFD is 161 feet. From Figure 7 for the back wall, the MFD is 124.94 feet, the HFD is 119.30 feet, and the ZFD is 128 feet. For this example, the siting distance of 125 feet exceeds the HFD values for both back wall and the roof. The hazardous fragment density for each surface must be determined. The hazardous fragment density can be determined in two ways. First, a direct interpolation between the HFD and ZFD (Equation 1) for a distance of 125 feet can be used.

$$1 - ((1 / (ZFD - HFD)) \times (125 - HFD)) \quad \text{EQUATION 1}$$

Equation 1 can produce an overly conservative number if the difference between the HFD and ZFD is large (more than a 30% difference). Second, the values can be read off of the graph if the level of accuracy can be assured. In most cases the concrete or masonry wall element hazardous fragment density is determined by the interpolation method and the hazardous fragment density

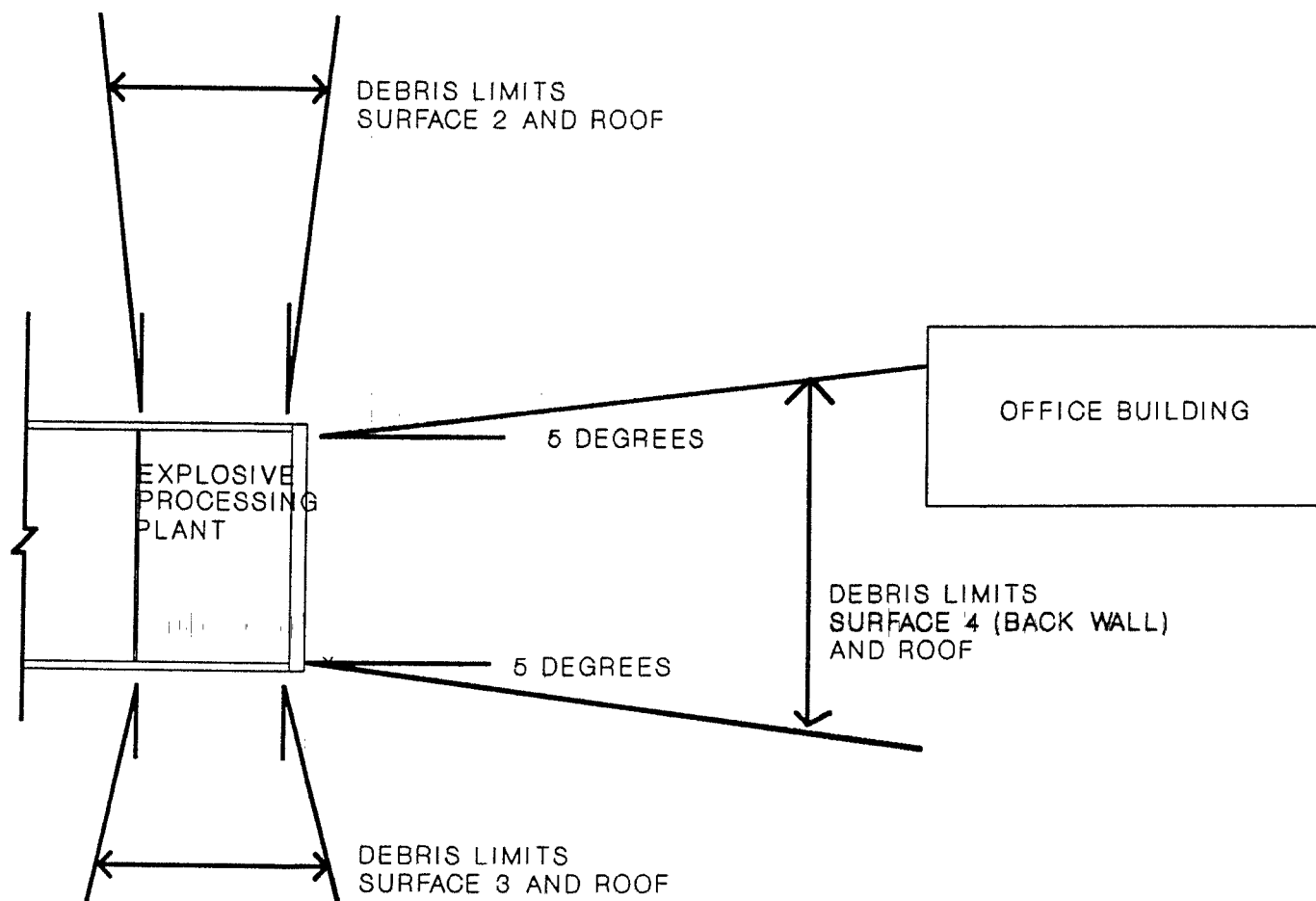


FIGURE 5 - EXAMPLE DEBRIS LIMITS

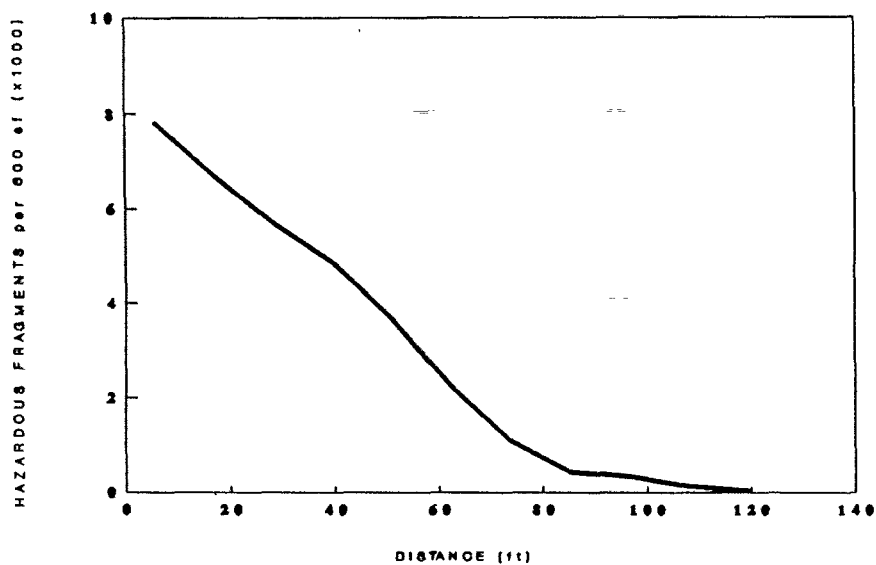
# ARMY BUILDING DEBRIS GRAPHS SELECTION CHART

| VENT SURFACE(S) |             | BAY SIZE<br>L x W x H |    | SURFACE      |    |     |    |              |    |     |    |              |    |     |    |              |    |    |  | R |
|-----------------|-------------|-----------------------|----|--------------|----|-----|----|--------------|----|-----|----|--------------|----|-----|----|--------------|----|----|--|---|
|                 |             |                       |    | 1            |    |     |    | 2            |    |     |    | 3            |    |     |    | 4            |    |    |  |   |
|                 |             |                       |    | CONSTRUCTION |    |     |    | CONSTRUCTION |    |     |    | CONSTRUCTION |    |     |    | CONSTRUCTION |    |    |  |   |
| CSF             | RC          | CMU                   | SB | CSF          | RC | CMU | SB | CSF          | RC | CMU | SB | CSF          | RC | CMU | SB | CSF          |    |    |  |   |
| R               | 20'x10'x20' |                       | 1  | 9            | 14 |     | 2  | 10           | 15 |     | 2  | 10           | 15 |     | 1  | 9            | 14 | 3  |  |   |
|                 | 20'x20'x20' |                       | 4  | 11           | 16 |     | 4  | 11           | 16 |     | 4  | 11           | 16 |     | 4  | 11           | 16 | 5  |  |   |
|                 | 20'x30'x20' |                       | 6  | 12           | 17 |     | 7  | 13           | 18 |     | 7  | 13           | 18 |     | 6  | 12           | 17 | 8  |  |   |
| R,1             | 20'x10'x20' | 19                    |    |              |    |     | 21 | 31           | 36 |     | 21 | 31           | 36 |     | 20 | 30           | 35 | 22 |  |   |
|                 | 20'x20'x20' | 23                    |    |              |    |     | 24 | 32           | 37 |     | 24 | 32           | 37 |     | 24 | 32           | 37 | 25 |  |   |
|                 | 20'x30'x20' | 26                    |    |              |    |     | 28 | 34           | 39 |     | 28 | 34           | 39 |     | 27 | 33           | 38 | 29 |  |   |
| R,1,2           | 20'x10'x20' | 40                    |    |              |    | 42  |    |              |    |     | 43 | 54           | 59 |     | 41 | 53           | 58 | 44 |  |   |
|                 | 20'x20'x20' | 45                    |    |              |    | 45  |    |              |    |     | 46 | 55           | 60 |     | 46 | 55           | 60 | 47 |  |   |
|                 | 20'x30'x20' | 48                    |    |              |    | 48  |    |              |    |     | 51 | 57           | 62 |     | 49 | 56           | 61 | 52 |  |   |

FIGURE 6 - GRAPH SELECTION CHART

ARMY BUILDING DEBRIS STUDY

GRAPH 27 - 25 lbs NEW



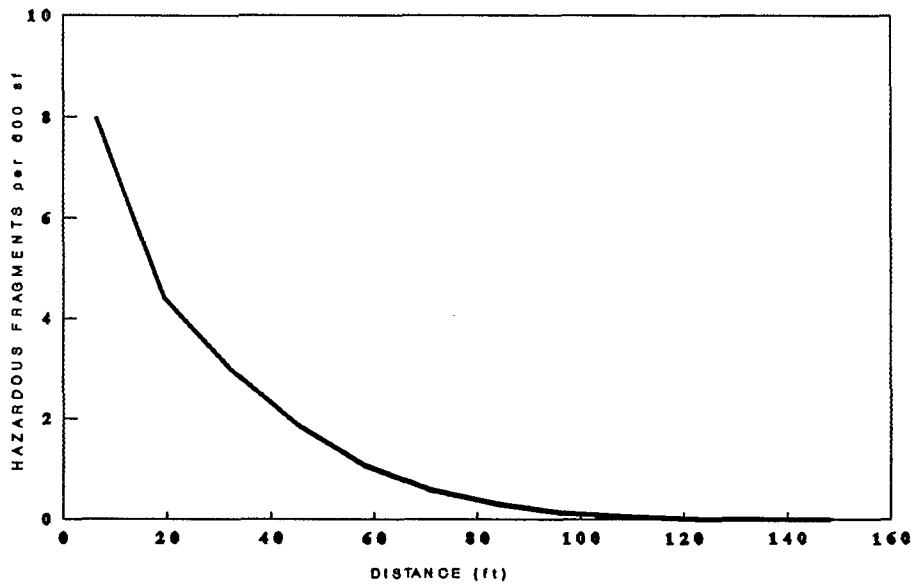
MAXIMUM PREDICTED DISTANCE (MFD) = 124.94 ft

MAXIMUM PREDICTED CRITICAL DISTANCE FOR CUMULATIVE RISK (HFD) = 119.30 ft

ZERO HAZARDOUS FRAGMENT DENSITY DISTANCE (ZFD) = 128 ft

**FIGURE 7 - FRAGMENT DENSITY GRAPH FOR BACK WALL**

ARMY BUILDING DEBRIS STUDY  
GRAPH 29 - 25 lbs NEW



MAXIMUM PREDICTED DISTANCE (MFD) = 144.2 ft  
MAXIMUM PREDICTED CRITICAL DISTANCE FOR CUMULATIVE RISK (HFD) = 57.96 ft  
ZERO HAZARDOUS FRAGMENT DENSITY DISTANCE (ZFD) = 161 ft

**FIGURE 8 - FRAGMENT DENSITY GRAPH FOR ROOF**

for the frangible metal decking surfaces are read directly off of the graph. Using Equation 1 for the wall a value is .35 hazardous fragments per 600 square feet is determined. Since the ZFD is much larger than the HFD, a direct interpolation between the two values would be unacceptable for the roof. Reading the graph on Figure 8 for a distance of 125 feet the hazardous fragment density for the roof is approximately .015 hazardous fragments per 600 square feet.

The aggregate (added) hazardous fragment density for the wall and the roof fragments is approximately .365 hazardous fragments per 600 square feet. The required IBD-F based upon 1 hazardous fragment per 600 square feet would be approximately 120 feet.

Reference 1 requires an inhabited building separation distance for overpressure (IBD-P) of K40 ( $40W^{1/3}$ ). For 25 pounds NEW this is equal to 117 feet. As previously stated, the default IBD-F between the explosive processing plant and the office building is 670 feet. However, since the hazardous fragment density at 125 feet from the process facility is under 1 hazardous fragment per 600 square feet, and IBD-P is less than 125 feet, the siting meets the requirements of Reference 1. Other factors that must be considered before final safety approval include hazards resulting from any primary fragments.

#### CONCLUSION

The study of Army building debris for DDESB is at approximately 60% stage of completion with a completion date of 30 September 1992. This study will provide a guide for determining the hazardous fragment density resulting from building debris of typical Army construction. The study will be usable by personnel with limited fragmentation analysis experience. As shown in the example, the required inhabited building separation distance (IBD-F) was reduced from 670 feet to approximately 120 feet. The use of the procedure developed in the study will enable efficient use of property by reducing the required separation distance for secondary fragments from the default Reference 1 values while maintaining personnel safety.