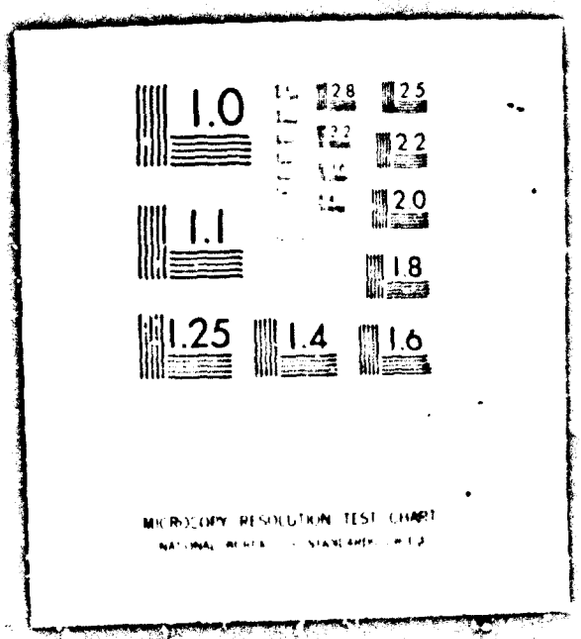

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A detailed, human ballistic mortality model has been developed at the Ballistic Research Laboratory which considers the interdependence of the different organs and tissues in a human. Variations by individuals in their vulnerabilities to ballistic damage are described by probability density functions. A Monte Carlo solution of the model for calculating the mortality rate of a large number of soldiers exposed to a common ballistic threat is outlined. Representative wounds are constructed in a human Phantom in →

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computerized enactments of battle scenes. The volumes of damage suffered by different organs are estimated by conducting random sampling passes over each wound. Individual vulnerabilities to damage are picked by sampling the appropriate probability density functions. The necessary equations are developed and the calculational procedure is outlined.

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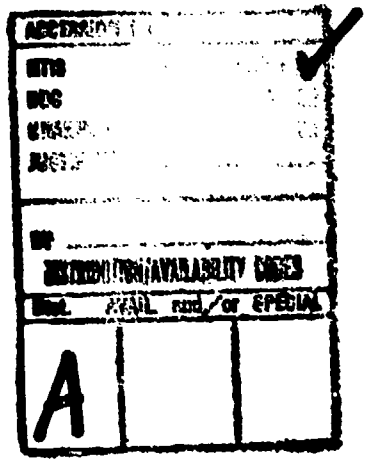

I. INTRODUCTION

A methodology which can be used to calculate the incapacitation rate of soldiers exposed to a ballistic threat is needed by the Army. These rates would be used by military planners to develop more efficient offensive weapons and to optimize the development of defensive material such as body armor. The results could also be used in the planning of both offensive and defensive tactics.

A statistical model which predicts the mortality rate of a large number of soldiers exposed to a ballistic threat has been developed by Beverly.[1] This model assumes that the mortality rate of a large number of soldiers in battle can be modeled by the phantom description of an average soldier. The Phantom will serve as the target for ballistic threats in computerized enactments of battle scenes. Representative projectiles are picked from the threat and projected toward the Phantom. A representative wound is constructed for each projectile that strikes the Phantom. The mortality probability is calculated for each wound and the mean probability is calculated for a large number of wounds to obtain the mortality rate expected from the threat.

The vulnerability (VI) to ballistic injury of an organ in an individual soldier is defined as the average threshold volume of tissue destruction in the organ that would lead to his death. This definition implies that the soldier has suffered no injury to his other organs. The vulnerability of the same organ in the Phantom is described by a probability density function (PDF) which predicts the frequency of occurrence of VI-values in the total soldier population.

A damage D_i is defined for an injury to the i^{th} organ in a soldier by

$$D_i = \frac{VW_i}{VI_i} \tag{1}$$

Where

VW_i = the volume of tissue destruction in the i^{th} organ.

VI_i = the mortal threshold volume of destruction in his i^{th} organ

An addition law is assumed to exist which can be used to accumulate the damages suffered by different organs to obtain a damage D for the total wound. This addition law is averaged over the total soldier

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1. *W.B. Beverly, "A Human Ballistic Mortality Model," to be published as as a BRL report.*

population to obtain the law which will be used in Phantom mortality calculations. This rule is assumed to be expressed analytically as

$$D = F(D_i) \tag{2A}$$

A wound in the Phantom whose damage is calculated to be 1 or greater is assumed to be mortal.

Baker et al[2,3] have conducted studies which indicate the function $F(D_i)$ can be approximated by the quadratic addition of organ damages. Equation 2A could then be expressed as

$$D = \left[\sum_{i}^{I} D_i^2\right]^{1/2} \tag{2B}$$

where

I = the number of organs in a soldier

i = the running index over organs

We will use the quadratic rule for the present but further studies should be conducted to verify its accuracy.

The mortality probability of the Phantom (or the mortality rate of the soldiers) for a particular wound is the product of the probability of the wound occurring and the death rate which would result from the wound. The mortality probability M of the Phantom, when he is exposed to a ballistic threat, is the average of his mortality probabilities for all possible wounds and is given in reference 1 as

$$M = \iiint_{\infty} BT[S(\vec{r}_1,\vec{p})\rightarrow w]\int_{\infty} H(D-1)\Phi_w(D)\ dDdV\ dP \tag{3A}$$

$$\Phi_w(D) = \int_{\infty}\cdots\int_{\infty}\Phi_1(VI_1)\cdots\Phi_I(VI_I)\int_{W}\delta[D-F(D_i)]dV_2\ d(VI_1)\cdots d(VI_I) \tag{3B}$$

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2. *S.P. Baker, B. O'Neil, W. Hadden, Jr., and W.B. Long, "The Injury Severity Score: A Method for Describing Patients with Multiple Injuries and Evaluating Emergency Care," THE JOURNAL OF TRAUMA, VOL. 14, No. 3, 1974.*

3. *S.P. Baker and B. O'Neil, "The Injury Severity Score: An Update," THE JOURNAL OF TRAUMA, VOL 16, No. 11, 1976.*

where

$\vec{r}_1$ = the origin of the projectile in the ballistic threat coordinate system

dV_1 = the infinitesimal volume in the ballistic threat coordinate system

$\vec{p}$ = the momentum of the projectile

dP = the infinitesimal volume in projectile momentum space

w = the wound volume in the Phantom

$S(\vec{r}_1, \vec{p})$ = the projectile source term normalized to one source projectile

$BT[S(\vec{r}_1, \vec{p}) \rightarrow w]$ = the function that describes the production of a wound by a projectile

$H(D-1)$ = the Heaviside step function

$\Phi_i(VI_i)$ = the probability density function which predicts the mortal volumes of tissue destruction VI_i for the i^{th} organ of soldiers

$\delta [D-F(D_i)]$ = the Kronecker delta function

dV_2 = the infinitesimal volume in the Phantom coordinate system.

It should be noted that the innermost integral of equation 3B is used to calculate the organ destruction volumes VW_i which are used to calculate the D_i. The quantity D is constant insofar as this integration is concerned and is used in the Kronecker delta functional to evaluate Φ as a function of D.

An analytic solution to equation 3 would usually require many cumbersome calculations. Such a heroic effort can be avoided by developing a completely stochastic solution where all calculations are relatively simple. However, the calculations will need to be repeated many times until estimates have been calculated to the desired statistical accuracy. The proposed Monte Carlo solution to the mortality model is briefly outlined here and will be discussed in detail in the next section of this report.

Representative projectiles are picked from the PDF's that describe the ballistic threat and are projected toward the Phantom. Representative

wounds, using the Dubin Cavity Model,[4] are constructed for those projectiles which strike the Phantom. An estimate of the volume of destruction inflicted upon each organ by a wound is obtained from the number of sample points, described later, lying within that organ. A threshold mortality volume VI_i is picked for each injured organ by sampling the appropriate PDF and is used to calculate the damage inflicted upon that organ. The total damage of the wound is calculated using equations 2A and 2B. A kill scored for a wound when its damage is one or greater and a survival is scored when its damage is less than one. The effects of a large number of similarly derived wounds are evaluated and averaged and the mortality rate of soldiers is calculated as the expected mortality probability of the Phantom.

II. THE STOCHASTIC SOLUTION

Section II of this report is divided into three sub-sections where the first sub-section is used to describe the general procedures used to calculate the mortality score of a wound. These procedures are discussed as if the step-by-step operation of a hypothetical computer program were being described. The Monte Carlo sampling techniques that are used here to pick VI-values for injured organs are described in detail in sub-section B. The Monte Carlo techniques that are used here to estimate the volumes of destroyed tissue in the injured organs are described in detail in sub-section C.

A. The General Solution

A projectile having momentum $\vec{p}$ is picked at origin $\vec{r}_1$, by sampling the PDF which describes the ballistic threat. The picking and tracking of projectiles which do not intercept the Phantom is reduced by picking only projectiles whose momentum vectors lie within the solid angle subtended by the Phantom-enclosing-sphere (see Figure 1).[5] The projectile-parameter picking techniques are not discussed in this study except to assume that the threat description can be efficiently sampled using standard sampling techniques.

A shotline is projected into the Phantom for each projectile that intercepts the Phantom. The deflection, break-up, and/or deformation of projectiles which strike bone tissue are not included in this study but should be ultimately considered. The present discussion will proceed as if the shotline of each projectile were a straight line.

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4. *H.C. Dubin, "A Cavitation Model for Kinetic Energy Projectiles Penetrating Gelatin," Ballistic Research Laboratories Memorandum Report No. 2423, December 1974.* (AD #B000910L)

5. *W.B. Beverly, "RAYMAN: A FORTRAN Computer Code for Tracing Rays Through a Detailed Human Phantom," Ballistic Research Laboratory Technical Report ARBRL-TR-2030, November 1977.* (AD #A051057)

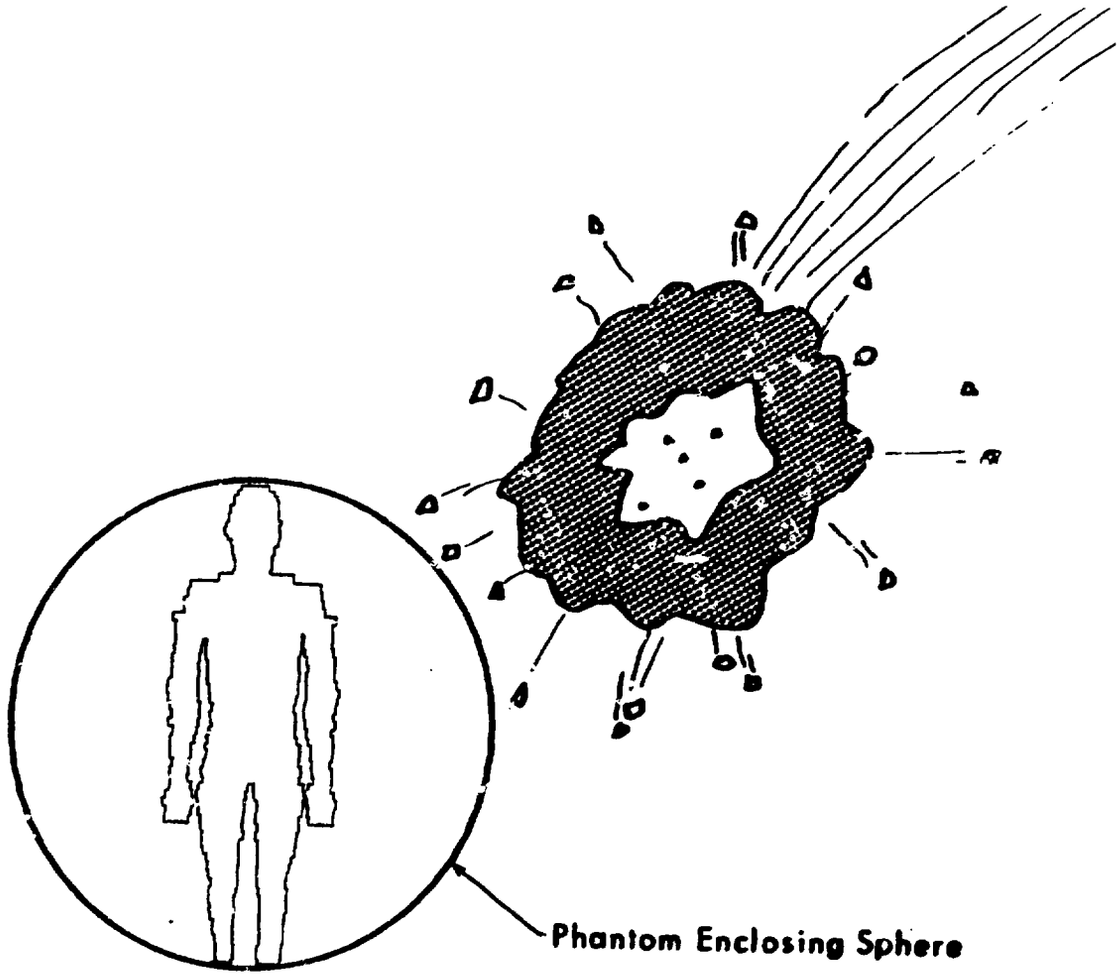

Figure 1. Typical Battle Scene

The point of entry and exit of a shotline into different organs along its path are located. The existing GIFT[6] computer program can be used to perform this calculation when the Phantom is described using the combinatorial geometry (COM-GEOM) technique. The geometry and input requirements used in GIFT are discussed in detail in the GIFT User's Manual.[7]

A shotline within an organ is divided into segments where all segments, except possibly the last one which includes the exit point, have equal lengths. A truncated right cone (TRC) is constructed about each segment to represent the wound. The radii of the cones are calculated using techniques developed in Reference 4. The radii of a cross section of a TRC will, in general, decrease with increasing penetration within an organ, Each cone is constructed using the physical characteristics of the tissue type (primary tissue) that is located on its axis. The cross section of a typical wound construction is displayed in Figure 2.

Points are picked with equal probability over the volume of a wound by conducting a sampling pass, in sequence, over each TRC within the wound. We assume that, on the average, one point is picked from each unit of volume. A score of 1 is assigned to each point which is embedded within the primary organ and this score is added to a bin reserved for that organ.

A point which lies outside the primary organ requires additional treatment as the energy flux reaching the point may not be sufficient to destroy the tissue. A projectile is assumed to not intercept the secondary organ at any point within the TRC being sampled. Some of the energy projected toward the secondary organ is reflected at the interface. This reflection results in a lower energy-flux level in the secondary organ than would be the case if no interface were present. Additionally, the energy-flux level required to destroy tissue in the secondary organ can differ from that required in the primary organ. These effects will cause the wound cavity in the secondary organ to differ from the cavity predicted for homogeneous tissue. The effect is shown in Figure 3 as an expanded view of Region B in Figure 2.

A radius vector is constructed from the sample point in the secondary organ to the axis of the TRC. The exit point from the primary

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6. *W. Guber, R. Nagel, P. Goldstein, P.S. Mittleman, and M. Kalos, "A Geometric Description Technique Suitable for Computer Analysis of Both the Nuclear and Conventional Vulnerability of Armored Military Vehicles," Mathematical Applications Group, Inc., Report No. MAGI 6701, August 1967.*

7. *L.A. Bains, Jr. and M.J. Reisinger, "The GIFT Code User Manual; VOL I, Introduction and Input Requirements," Ballistic Research Laboratory Report No. 1802, July 1975.* (AD #B006037L)

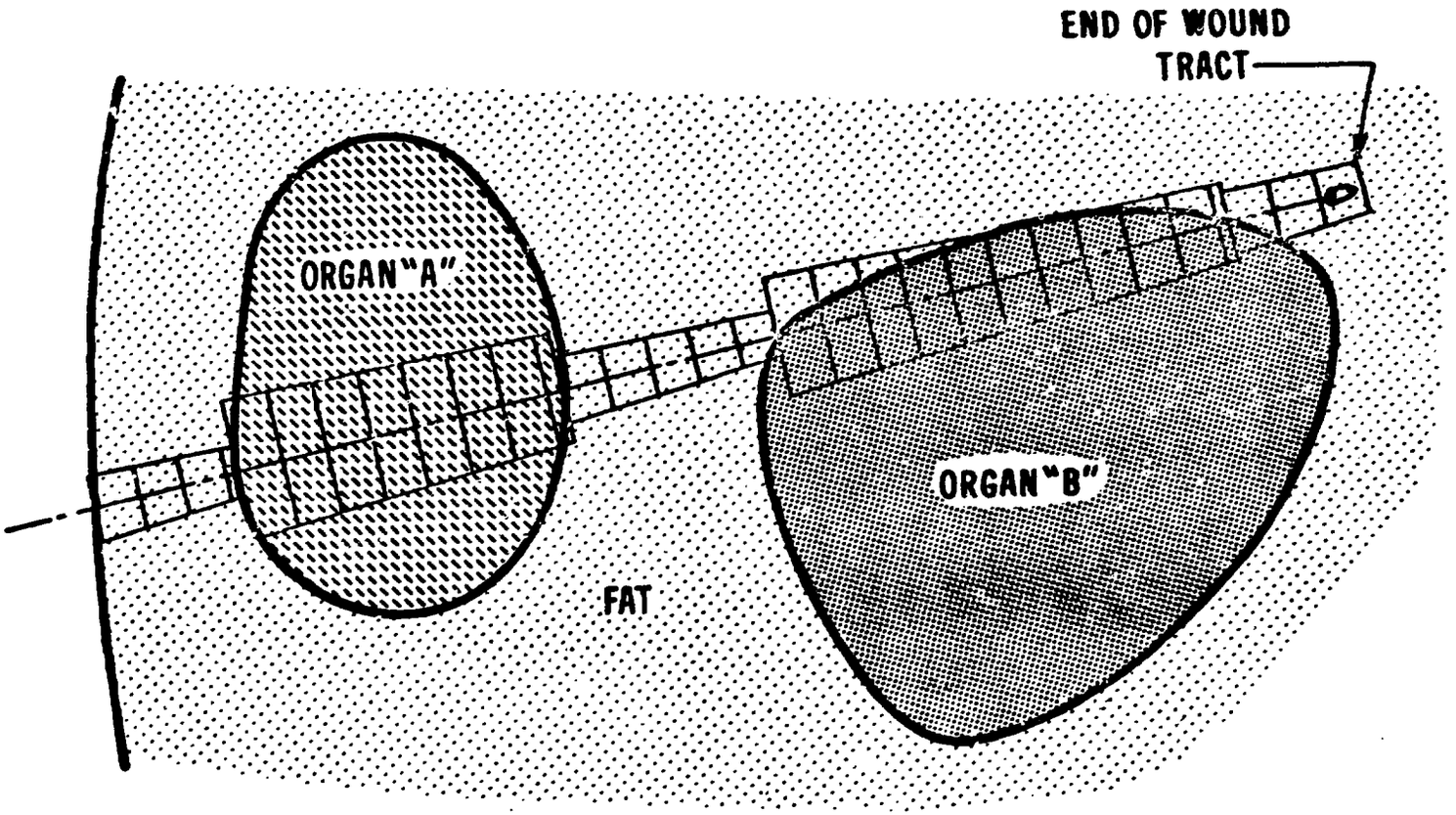

Figure 2. Longitudinal Cross Section of a Wound Tract

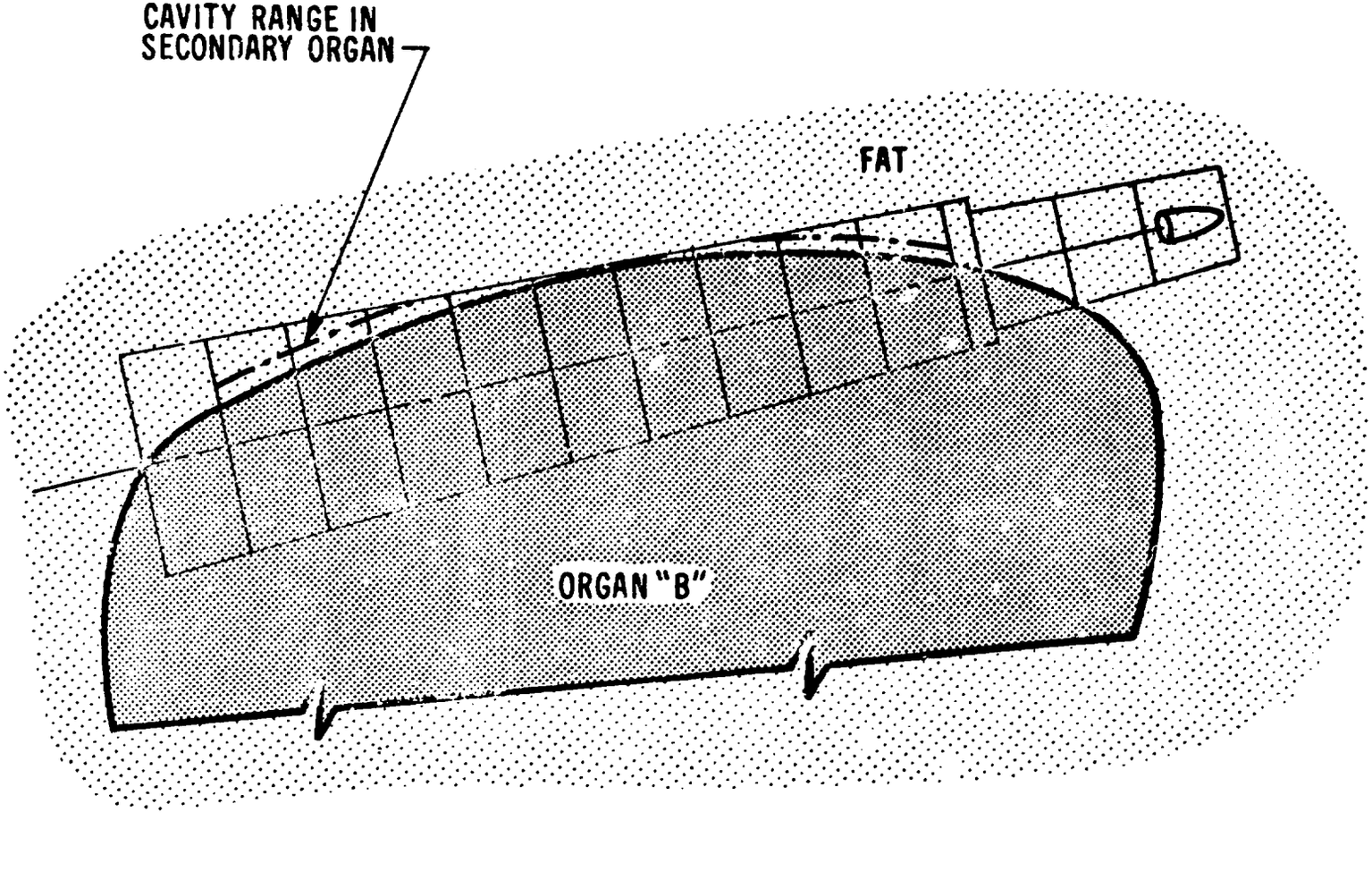

Figure 3. Albedo Correction to Wound Cavity

organ along this ray is then located. The energy-reflection coefficient of the two organs is used to calculate the energy flux transmitted across the interface. The energy flux transmitted to the sample point is calculated and a score of 1 is tallied for the secondary organ when the flux is sufficient to destory the secondary tissue. A zero score is tallied when the energy flux arriving at the point is not sufficient to destroy the tissue.

A stochastic estimate of the volume of tissue destroyed in each organ is calculated using the results of several sampling passes over a wound volume. Assuming that one point was picked per pass from each unit of volume, an estimate of the volume of tissue destroyed in the i^{th} organ may be calculated using

$$\overline{VW}_i = \frac{1}{K}\sum^{K} V_{ik} \tag{4}$$

where

k = the running index over sampling passes

K = the number of sampling passes

V_{ik} = the total number of points (scores) accumulated for the i^{th} organ during the k^{th} pass.

The standard deviation $\delta(\overline{VW}_i)$ of this estimate is calculated using [8]

$$\delta(\overline{VW}_i) = \left[\frac{\sum^{K} V_{ik}^2 - K\,\overline{VW}_i^{\,2}}{K(K-1)}\right]^{1/2} \tag{5}$$

The bar is placed over a variable to show that a mean estimate of its value is being used.

A value of VI_i of each injured organ is picked by sampling its probability density function. The damage to each injured organ (equation 1) and the total damage (equation 2B) are calculated yielding

$$\overline{D} = \left[\sum^{I}\left(\frac{\overline{VW}_i}{VI_i}\right)^2\right]^{1/2} = \left[\sum \overline{D}_i^{\,2}\right]^{1/2} \tag{6A}$$

8. *Y. Beers, "Introduction to the Theory of Errors," Addison-Wesley Publishing Co., Inc., 1953.*

The variances of these damage estimates are derived to be[8]

$$\delta^2\overline{D} = \frac{1}{D^2} \sum^{I} \left[\frac{\overline{VW}_i \cdot \delta(\overline{VW}_i)}{(\overline{Vt}_i)} \right]^2 \qquad (6B)$$

A criterion is set for the minimum acceptable statistical uncertainty in $\overline{D}$. Another series of sampling sweeps will be conducted when this criterion is not reached during the current series. A kill is then scored for a wound whose damage estimate is one or greater.

As noted earlier in this section, only those projectiles which have a high probability of striking the Phantom are picked and tracked. The mortality rate due to a threat whose projectiles are emitted isotropically about their origin points is given by

$$M = \frac{1}{4\pi N} \sum^{N} \Omega_n(\vec{r}_1)\, H(D_n - 1) \qquad (7)$$

where

n = the running index over projectile histories

N = the number of projectile histories

D_n = the total damage of the n^{th} wound

$\Omega_n(\vec{r}_1)$ = the solid angle subtended by the Phantom-enclosing-sphere at the projectile origin

$H(D_n - 1)$ = Heaviside step function.

The normalization of the mortality rate for an anisotropic source term is not discussed in the present study.

The general logic used by the hypothetical computer program to calculate an estimate of the mortality rate due to a ballistic threat is now outlined. Detailed discussions of the Monte Carlo techniques used here are given in Sections II.B and II.C.

1. Pick a projectile having momentum $\vec{p}$ at origin $\vec{r}_1$ by sampling the ballistic threat probability density functions.

2. Track the projectile through the Phantom-enclosing-sphere and construct a representative wound if the projectile strikes the Phantom.

3. Zero the score-hod array HOD, the score accumulation array SCORE, and the squared-score accumulation array SCORE2. The array HOD

is used to accumulate the scores acquired by each organ during a pass. The arrays SCORE and SCORE2 are used to accumulate the scores and squared scores gathered over several passes.

4. Conduct a sampling pass over the wound where points are picked with equal probability over the volume of the wound. Determine the organ in which each point is embedded.

5. Add the score of each sample point to the HOD bin reserved for the organ in which the point is embedded. A non-zero score is the reciprocal of sample-point density. This definition of score value yielded the scores of 1 and 0 which were used earlier in this report. A sample-point density of one point per unit volume was used in this case.

6. At the completion of each pass, add the scores accumulated in HOD to SCORE. Square each score in HOD and add the result to SCORE2. A bin is reserved in SCORE and SCORE2 for each injured organ.

7. Zero all bins in HOD and conduct K-1 similar score passes.

8. Calculate an estimate of the volume of tissue destruction using the current version of equation 4,

$$\overline{VW}_i = \frac{SCORE(i)}{K} \quad . \tag{8A}$$

9. Calculate an estimate of the variance $\delta^2(\overline{VW}_i)$ of each volume estimate using the current version of equation 5,

$$\delta^2(\overline{VW}_i) = \frac{SCORE2(i) - K \cdot VW}{K(K-1)} \tag{8B}$$

10. Pick a mortal volume VI for each injured organ by sampling the appropriate PDF. Calculate an estimate of the damage (equation 1) and the standard deviation of the damage estimate for each injured organ. The damage-estimate variance is given by

$$\delta^2\overline{D} = \left[\frac{\delta(VW_i)}{VI}\right]^2 \tag{8C}$$

11. Calculate an estimate of the total damage $\overline{D}$ of the wound (equation 2B) and the standard deviation of the damage estimate (equation 6B).

12. Compare the variance of the damage estimate (equation 8C) with the maximum variance threshold criterion. Proceed to the next step when the variance is less than this threshold value. Conduct another series of sweeps over the wound when the variance is too large.

13. A kill is scored when the damage equals or exceeds the mortal damage. The geometrical normalization is calculated for a killing projectile using equation 7.

14. Conduct similar calculations until N projectiles histories have been completed. The killing probability of the threat is then calculated using equation 7.

B. Sampling the VI Probability Density Functions

The probability density function of the mortal volumes of tissue destruction is measured or calculated as a histogram. These functions can be derived by an analysis of gunshot case histories in combination with assessments by shock-trauma doctors of wound effects. Assuming the histogramic form, Sample VI values can be picked using the fundamental principle of Monte Carlo (FPMC).[9] The application of this principle yields a sample value given by

$$\int_0^{VI_i} \Phi_i(VI)d(VI) = RN(0,1) \qquad (9)$$

where

RN(0,1) = a random number picked with equal probability on the range of 0 to 1

VI_i = the picked VI value for the i^{th} organ

Each $\Phi_i(VI)$ is normalized to one over its complete range of values.

The sampling process is hastened by evaluating the integral in equation (9) at each histogramic bin interval and storing the results in a VI versus CDF (cumulative distribution function) table. These values are assumed to be stored in ascending order where the last CDF-value in each table is one. The plot of a typical PDF and its associated CDF are displayed in Figure 4.

A sample VI-value may now be picked using a procedure where the only operations are the comparison of the table CDF-values with a random number followed by a linear interpolation. This procedure is illustrated in Figure 4 and is outlined below. We will assume that the VI versus CDF values of the organ in this example are stored in the CUM array. It should be noted that J and K which are used here apply only to equation 10 and this definition should not be used elsewhere in this report. The VI values are stored in the top row of the CUM matrix (array) and the CDF are stored in the bottom row of the CUM array.

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9. *Y.A. Schreider, "The Monte Carlo Method," Pergamon Press, 1966.*

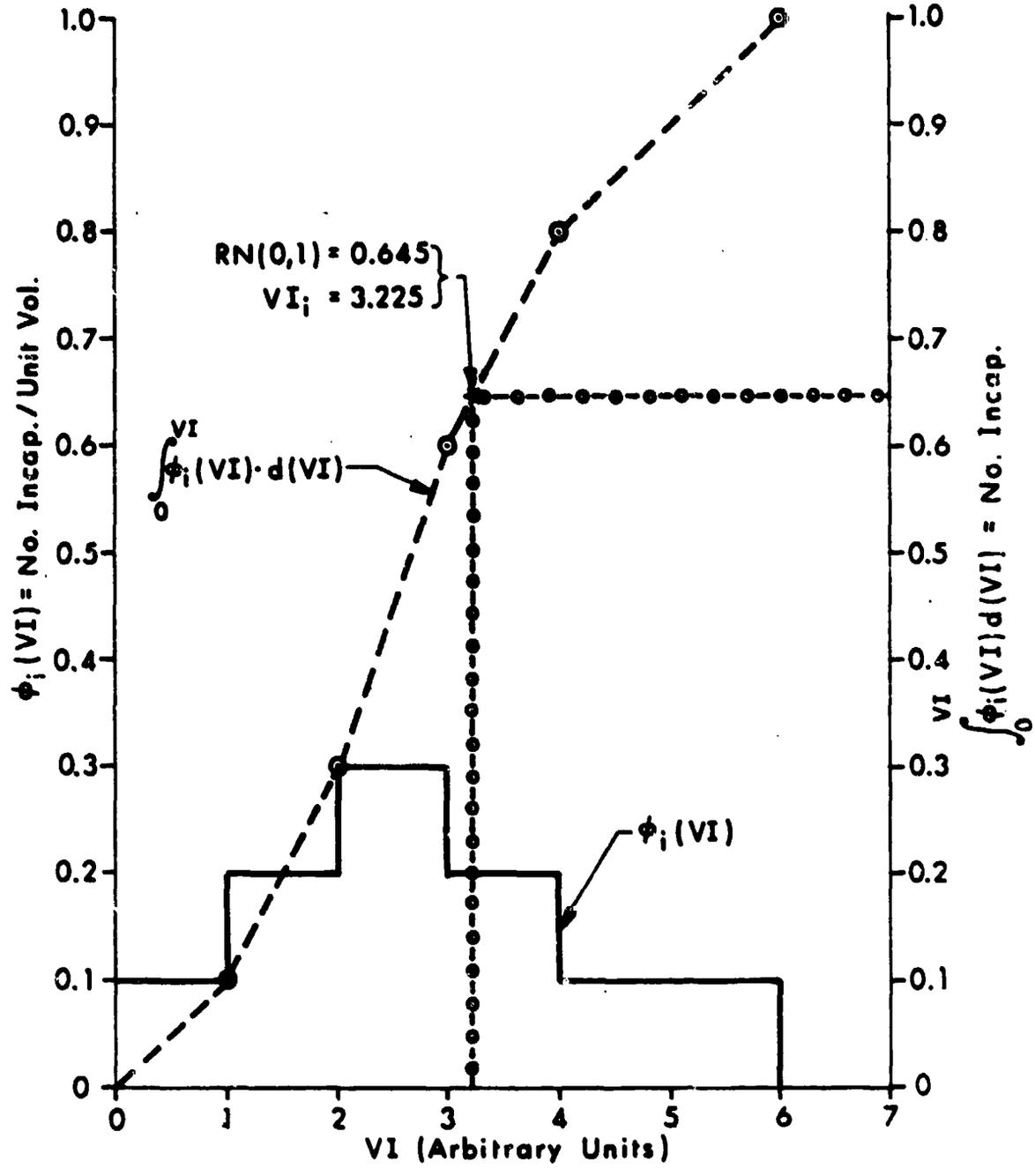

Figure 4. Typical PDF and CDF

1. Calculate a random number RN(0,1).

2. Locate the adjacent pair of CDF values in CUM which bound RN(0,1). The smallest value is indexed by J and the largest value is indexed by K.

3. The sample VI-value is calculated using

$$VI_i = CUM(1,J) + \frac{[RN(0,1) - CUM(2,J)][CUM(1,K) - CUM(1,J)]}{[CUM(2,K) - CUM(2,J)]} \qquad (10)$$

C. The Estimation of Organ Destruction Volumes

The volume of tissue destroyed in each organ of the Phantom is also estimated stochastically. This estimate is calculated by picking points with equal probability over the volume of the wound and identifying the organs in which they are embedded. An estimate of the volume of tissue destroyed in a particular organ is proportional to the number of non-zero score points that are located in the organ. The statistical accuracy of this estimate depends upon the density of sampling points picked within the wound and will converge toward the true value as the density of sample points becomes large.

A wound is initially constructed as a series of coaxial, truncated right cones. The conical geometry is modified at an organ interface by the albedo correction but sampling points are still picked with equal probability over the volume of the original cone. However, a zero score is tallied for points that lie outside the modified wound volume.

A TRC is divided into two parts to facilitate the calculation of sample points (see Figure 5). A coaxial cylinder (RCC), which has a radius equal to the radius at the small end of the TRC, is constructed in the TRC. Sampling points can be easily picked over this volume by using the FPMC. The picking of sample points in the remainder of a cone (REM) will require the use of the less efficient rejection technique.[9] A sampling pass over a TRC will be first conducted over its RCC and then over its REM. The calculation of an organ destruction volume estimate is now discussed in step-by-step detail.

1. Calculate the volume of the TRC and identify this quantity as VCN. Calculate the volume of the enclosed cylinder and identify this quantity as VCY. Truncate VCN to an integar and identify this number as M. This definition of M is only used in this sequence of steps and should not be confused with the mortality rate M used earlier in this report. Start an associated running index m at 1.

2. Calculate a random number $RN_1(0,1)$. The subscript is added to the usual identification of a random number to identify its origin for

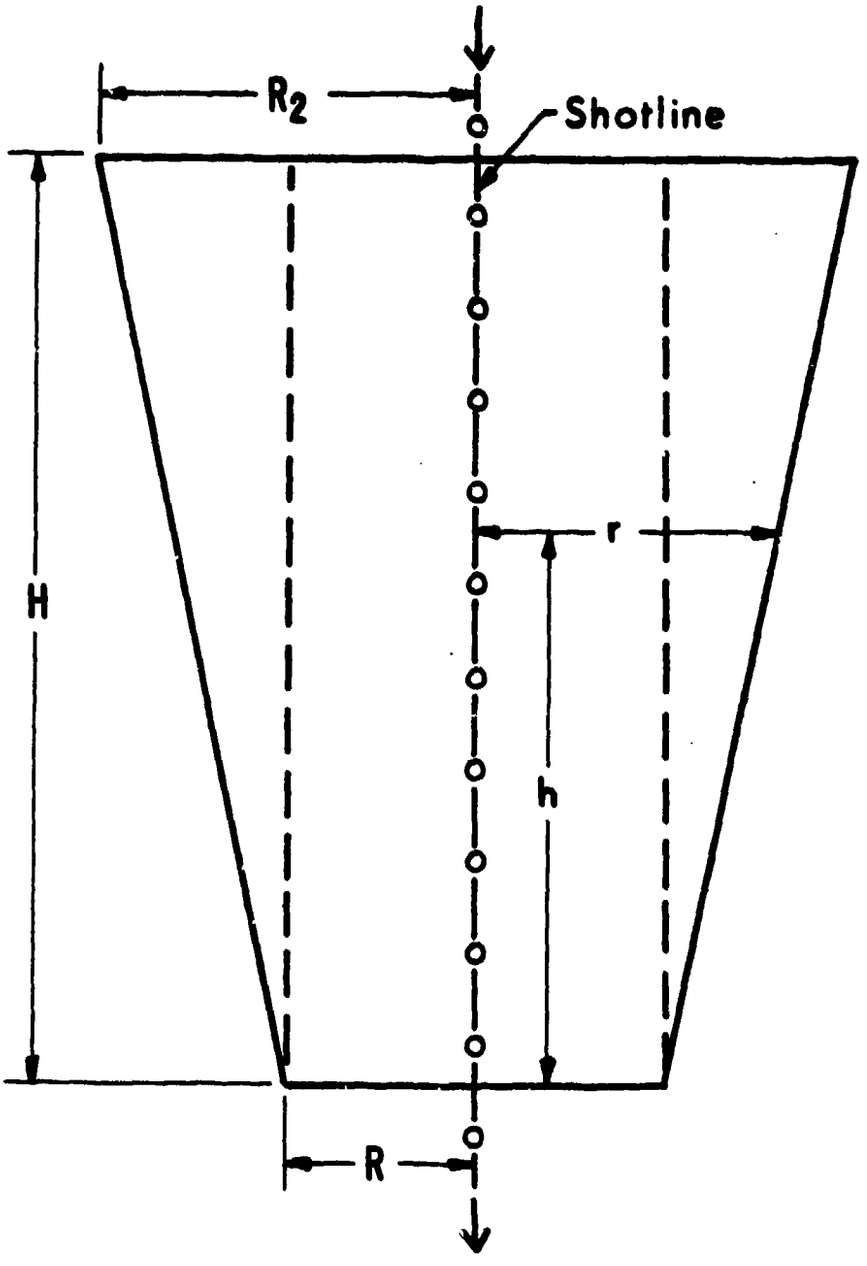

Figure 5. The Geometry of a Wound Cell

those cases where a particular random number may be translated to a new range and reused. All unsubscripted random numbers are used once and discarded.

3. Compare $RN_1(m-1,m)$ with VCY. Go to step 1 of the REM sampling if RN(m-1,m) is greater than VCY. An outline of REM sampling immediately follows the outline of RCC sampling. We have assumed that the sampling density is one point per unit volume.

4. The PDF of points in a volume as a function of one of the coordinates is proportional to the cross-sectional area of the volume as a function of the same coordinate. This concept, when applied to the RCC enclosed by a TRC, permits the FPMC to be used to calculate the penetration h_m of a quadruplet of sample points by solving

$$\int_0^{h_m} \pi R^2 dh = RN(m-1,m) \tag{11}$$

where

h = the penetration along the axis of the RCC as measured from the small end of the associated TRC

R = the radius of the cylinder.

5. The PDF of points on a plane area as a function of one of the coordinates is proportional to the length of the curve within the area defined by the same coordinate. This concept permits the FPMC to be used to calculate the radius r_m of the quadruplet of sample points, located on the cross section in the RCC which is defined by h_m, by solving

$$\int_0^{\gamma_m} 2\pi r d = \pi R^2 \cdot RN(0,1) \tag{12}$$

where

r = the radius of a concentric circle within the specified circular cross section of the RCC.

6. Locate an azimuthal reference on the circle that has been defined in steps 4 and 5. A sample point is picked with equal probability on each 90° arc of the circle by solving

$$\int_0^{\theta_{jm}} d\theta = \frac{\pi}{2} \cdot RN_2(j-1,j) \tag{13}$$

where

ϑ = the azimuthal angle (radians)

j = the circle quadrant index.

7. Transform each sample point $P(h_m, r_m, \theta_{jm})$ into the Phantom Cartesian coordinate system to obtain four points $(P_{jm}(x,y,z)$. Determine the organ in which each point is embedded. The sample point density is four points per unit volume so the non-zero scores are now 0.25. Add a score of 0.25 to the appropriate HOD bin for each point which lies within the primary organ. Go to step 9 if all four points lie within the primary organ.

8. Calculate the energy flux which is transmitted from the shotline in the primary point in the secondary organ. Add a score of 0.25 to the appropriate bin of the HOD array when the energy flux at the point exceeds the destruction threshold value. A zero score is added to the HOD array when the energy flux at the point is less than the destruction threshold value.

9. This completes the sampling in the first unit volume of the RCC. Translate $RN_1(m-1,m)$ to a new range using

$$RN_1(m,m+1) = RN_1(m-1,m) + 1 . \qquad (14)$$

Add 1 to the running index m and return to step 3. It should be noted that the index m is incremented after the translation of the random number so that $RN_1(m,m+1)$ as used in equation 14 is equal to $RN_1(m,m-1,m)$ as used in step 3 when the return is completed.

The sampling for one pass through the RCC is completed when a jump to the first step of REM-sampling is directed. A sample point in a REM is also chosen by picking, in order, its penetration h_m, radium r_m, and azimuth angles θ_{jm}. The coordinates r_m and θ_{jm} are calculated using the same techniques that were used to calculate these picks during RCC sampling. However, using the FPMC to pick a penetration h_m would require finding the roots of a cubic equation. This difficult calculation is avoided by using the rejection technique of Reference 9 to pick the penetration coordinate of sampled points. The procedure used to pick sample points in a REM is outlined below.

1. Compare the running index m with M and go to step 5 if they are equal.

2. The PDF of points in a REM as a function of the penetration along its axis (Figure 5) is given by

$$PDF(h) = CA(h) \tag{15A}$$

where

h = the penetration along the axis of the REM as measured from the small end of the TRC

PDF(h) = the PDF of points in a REM

C = the normalization constant.

The area of a cross section in a REM is the difference between the area of the associated cross section of the TRC and the area of the enclosed cross section of the RCC and is given by

$$A(h) = \pi r^2 - \pi R^2 = Sh(2R + Sh) \tag{15B}$$

$$S = \frac{R2 - R}{H} \tag{15C}$$

where

R = the radius of the TRC at its small end

R2 = the radius of the TRC at its large end

H = the height of the REB (and TRC).

The procedure for picking the h_m-coordinate of a sample point is illustrated graphically in Figure 6 and is discussed from that perspective in the following step-by-step outline.

2A. Plot the function PDF(h) over its range of 0 to H.

2B. Construct a rectangle that barely enclosed this curve.

2C. Pick a point $P(h_m, PDF_m)$ at any location within the rectangle with equal probability. The coordinates of the point are calculated using

$$h_m = H \cdot RN(0,1) \tag{16A}$$

$$PDF_m = PDF(H) \cdot RN(0,1) \tag{16B}$$

2D. The quantity h_m is a good choice when $P(h_m, PDF_m)$ lies under the curve (PDF(h). Proceed to the next step when this favorable event

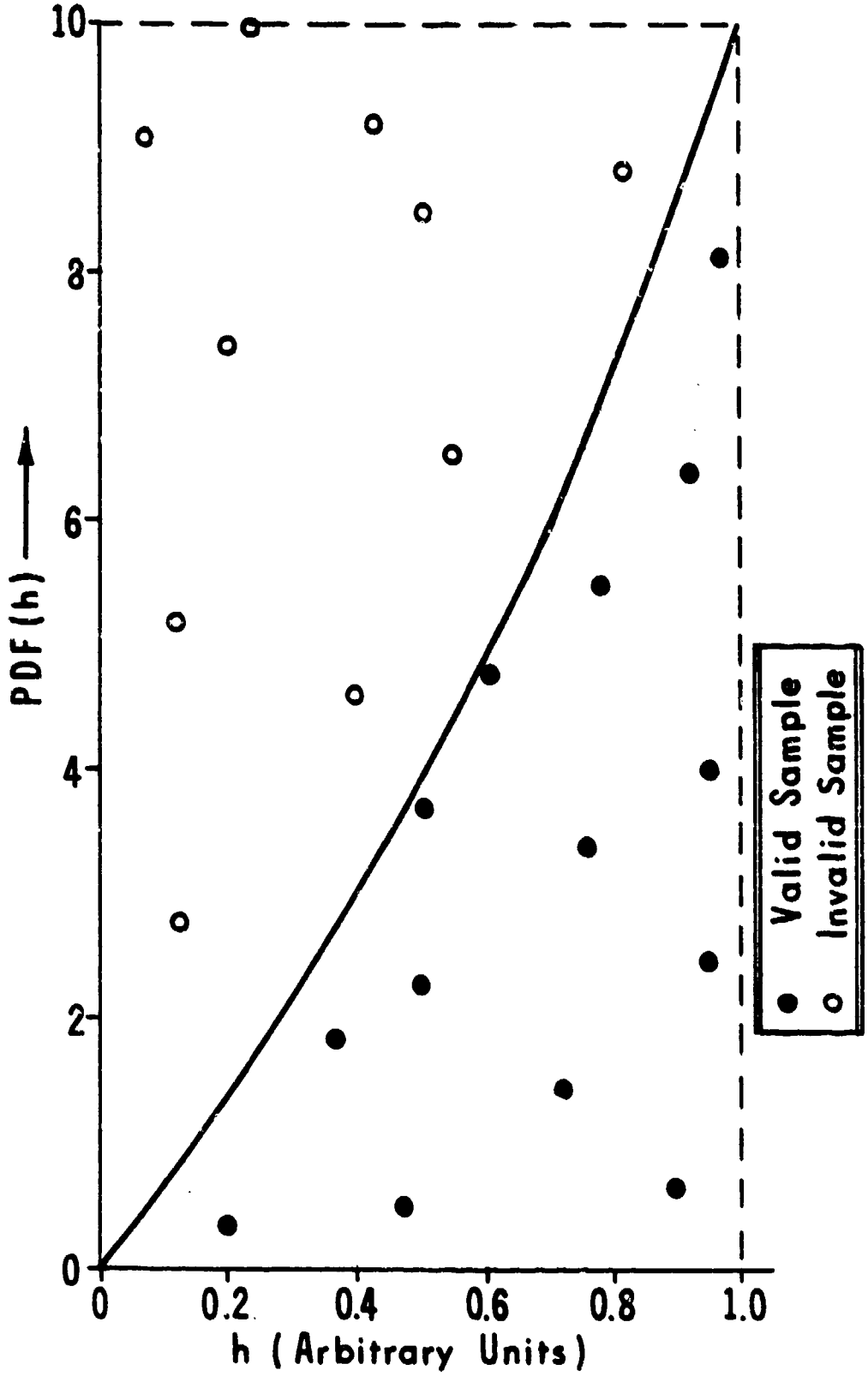

Figure 6. The Rejection Technique Used to Sample a REM

occurs. Discard the current point $P(h_m, PDF_m)$ when it lies outside the curve and pick a new point by returning to step 2C. Repeat step 2C until a favorable point is picked.

3. Calculate the radius coordinate r_m of the sample points using

$$\int_R^{r_m} 2\pi r dr = \pi\left[(R_2)^2 - R_m^2\right] \cdot RN(0,1) \tag{17A}$$

$$R_m = R + \frac{h_m(R_2 - R)}{H} \tag{17B}$$

The reader should note that the integration interval is changed in equation (17A) from that used in equation (12) for RCC sampling.

4. The azimuthal angle coordinates of four sample points are picked using the same techniques that were outlined in the RCC sampling discussion. Similarly, the embedding organs of sample points are identified and scores are calculated and tallied. The running index is incremented by one at the completion of each tallying of the scores for four points and the calculation flow is returned to step 1 of the REM sampling.

5. A fractional weight W is assigned to the last four sample points and given by

$$W = VCN - M \tag{18}$$

where VCN is the TRC volume and M is the largest integer in VCN. The coordinates of these last points are picked using steps 2-4 but the scores now tallied are either W/4 or 0.

This completes the outline of one sampling pass through a TRC. Each TRC in a wound will be similarly sampled during a pass and an adequate number of passes will be conducted over the wound to obtain damage estimates having the desired statistical accuracy.

III. PROGRESS AND PROGNOSIS

A Monte Carlo solution to the human ballistic mortality model has been outlined. Sampling procedures which can be used to pick variant values are developed and discussed. Procedures are developed for calculating the confidence limits on damage estimates. Adequate sampling of a wound volume is assured by comparing the variance of a damage estimate with the maximum acceptable variance criterion. Further sampling of a wound volume would then be automatically directed by the computer program until the variance criterion was met.

The probability density functions that predict the incapacitating volumes of destruction for the different organs have not been evaluated due to lack of experimental data. A data bank of hospital gunshot cases which could be used for this purpose is being collected by Sacco and Sturdivan[10] but the acquisition is not complete at this time. The precision of such data may not be very high since attending physicians focus their attention upon saving the life of the patients rather than making accurate experimental measurements. Mortality assessments of wounds by shock trauma doctors have been collected by Kokinakis and Cooper[11] but the latter data is not adequate within itself to derive the necessary probability density functions. The best set of probability density functions will probably be obtained by utilizing both data sources.

Many of the subroutines and much of the logic required by a mortality computer code exist in other codes.[1,4,5,6] These subroutines and logic will need to be assimilated into one computer code.

A COM-GEOM description of the Air Force Man[12] is being considered at the Ballistic Research Laboratory (BRL). If completed, this description would replace the currently used Computer Man.[13] It is expected that this new Phantom, unnamed at present, will provide a significantly more accurate description of a representative soldier.

Much work is still needed to achieve a working, mortality-calculational methodology. Some aspects of the present study will probably need to be changed or refined. The author hopes that this study will contribute to the achievement of this goal.

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10. *W. Sacco and L. Sturdivan, Unpublished Data.*

11. *W. Kokinakis and W. Cooper, Unpublished Shock Trauma Assessments.*

12. *Kase, P.G., "Computerized Anatomical Model Man," Martin Marietta Corporation Technical Report No. AFWL-TR-69-161, January 1970.*

13. *C.A. Stanley and M. Brown, "A Computer Man Anatomical Model," Ballistic Research Laboratory Report ARBRL TR No. 02060, May 1978.* (AD #A056564)

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