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A MUNITION EXPENDITURES MODULE
KWIK

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Abstract

The EOSAEL87 KWIK module is a smoke munition expenditure algorithm that predicts the required number of white phosphorus (WP) or hexachloroethane (HC) howitzer and mortar smoke munitions necessary to reduce the probability of target detection to a given level. The module uses threshold transmittance values of 0.10 for visible and near-infrared (IR) and 0.05 for mid- and far-IR wavelengths. Mathematical solutions used in KWIK for atmospheric transmission through smoke, microscale diffusion, and munition expenditure calculations are given in the description of the model development.

The post Smoke Week VII updates and improves derived by using the Combined Obscuration Model for Battlefield-Induced Contaminants model are included in the report. The report also provides detailed user instructions and sample tabular output showing the number of initial and sustaining rounds, fire intervals, and shell separations needed to produce a screen of input length and duration of WP smoke (for visible, near-,mid-, and far-IR wavelengths) and HC smoke (for visible, near-IR wavelengths) using eight inventory munitions.

Chapter 1

TECHNICAL DOCUMENTATION

1.1 Introduction

KWIK, an acronym for crosswind integrated concentration, is a smoke munitions expenditures model developed by Umstead, Peñ, and Hansen [UnH79] for the U.S. Army Atmospheric Sciences Laboratory. This report includes the latest improvements to the model, which is designed for the use with eight inventory munitions (listed in table 1). Also, new data have been included on munition characteristics, mass extinction coefficients, yeild factors, and munition efficiencies obtained from the Electro-Optical System Atmospheric Effects Library's (EOSAEL) Combined Obscuration Model for Battlefield-Induced Contaminants (COMBIC). COMBIC has also been used to verify and modify munition sustaining rates of fire.

The EOSAEL87 KWIK module contains six subroutines, which are described in the user's guide portion of this report. KWIK munition calculations predict the required number of white phosphorus (WP) or hexachloroethane (HC) howitzer and mortar munitions necessary to reduce the probability of target detection to a given level. The threshold transmittance levels used by the module are 0.10 for visible and near-infrared (IR) and 0.05 for mid- and far-IR wavelengths. Mathematical solutions for atmospheric transmission through smoke, microscale diffusion, and munition expenditure calculations are given in the description of the model development.

User instructions are provided as well as sample tabular output showing the number of initial and sustaining rounds, fire intervals, and shell separations required to produce a smoke screen of input length and duration of WP smoke (visible, near-, mid-, and far-IR wavelengths) and HC smoke (visible and near-IR wavelengths).

1.2 Total Integrated Path Concentration (CL) for KWIK Munition Expenditures Model

The KWIK munitions expenditures model uses the atmospheric transmittance threshold values of 0.10 for visible and near-IR and 0.05 for mid- and far-IR wavelengths. Equation 1.1, for the total transmittance, contains the effects of both the natural atmosphere and smoke.

$$T_{\text{tot}} = T_{\text{adv}} T_{\text{smoke}} \tag{1.1}$$

The adverse weather part (T_{adv}) of equation 1.1 (including reduction due to haze, fog, rain, or snow) is obtained from the EOSAEL XSCALE model, which is called by KWIK. The remaining transmittance (T_{smoke}) is then converted to total CL in grams per square meter through application of the mass extinction coefficients for the applicable smoke and wavelength bands.

Table 1.1: MUNITION FILL WEIGHTS AND BASIC CHARACTERISTICS

Munition type	Fill (lb)	weight (g)	Burn time (s)	Nominal burst diameter (m)	Source strength	Efficiency (%)	Initial standard deviation (m) σ_{y0}	σ_{z0}
105-mm HC M84A1 Projectile	4.71	2136.4	120	NA	17.8 gs^{-1}	70	NA	NA
Submunition: 3 HC Canisters	1.57	712.1	120	NA	5.9gs^{-1}	70	NA	NA
155-mm HC M116B1 Projectile	19.0	8619.3	100	NA	86.2gs^{-1}	70	NA	NA
Submunitions:								
3 M1 Canisters	5.4	7348.2	100	NA	73.5gs^{-1}	70	NA	NA
1 M2 Canister	2.8	1270.1	70	NA	18.1gs^{-1}	70	NA	NA
105-mm WP M60A2 Cartridge	3.83	1737.3	75	56	1737g	100	6.4	2.1
155-mm WP M110E2 Projectile	15.60	7076.0	60	66	7067g	100	7.9	2.6
81-mm WP M375A2 Cartridge	1.60	725.7	45	50	725.7g	100	4.2	1.44
4.2-in WP M328A1 Cartridge	8.14	3692.2	45	64	3692.2g	100	6.6	2.44
155-mm WP M825 Projectile (116 felt wedges)	16.17	7334.0	612	110	14.67gs^{-1}	74	NA	NA
81-mm RP XM819 Cartridge (28 felt wedges)	2.834	1285.5	240	49	4.94	48	NA	NA

Table 1.2: MASS EXTINCTION COEFFICIENTS FOR HC AND WP SMOKES

$$\begin{aligned}
& \underline{0.4\text{–}0.7\mu\text{m(Visible)}} \\
\text{HC: Ext. Coeff} =\ & 2.493 + 0.05733R_H - 6.791\times10^{-4}R_H^2 \\
\text{WP: Ext. Coeff} =\ & 2.341 + 0.06589R_H - 6.226\times10^{-4}R_H^2 \\
& \underline{1.06\mu\text{m(Near-R)}} \\
\text{HC: Ext. Coeff} =\ & 1.222 + 0.03643R_H - 3.050\times10^{-4}R_H^2 \\
\text{WP: Ext. Coeff} =\ & 1.39 - 0.0107R_H + 2,077\times10^{-4}R_H^2 \\
& \underline{3.0\text{–}5.0\mu\text{m(Mid-IR)}} \\
\text{WP: Ext. Coeff} =\ & 0.2124 + 0.01065R_H - 2.889\times10^{-4}R_H^2 + 2.17\times10^{-6}R_H^3 \\
& \underline{8.0\text{–}12.0\mu\text{m(Far-IR)}} \\
\text{WP:}R_H < 50 : \text{Ext.Coeff} =\ & 0.3756 \\
R^H > 50 : \text{Ext.Coeff} =\ & 0.7123 - 0.01678R_H + 2.817\times10^{-4}R_H^2 - 1.618\times10^{-6}R_H^3
\end{aligned}$$

$$CL = \ln(T_{\text{smoke}})/-\alpha, \tag{1.2}$$

where α is the mass extinction coefficient.

Hoock et al.[HSD84] show that α depends on wavelength and relative humidity (RH). Table 2 shows the mass extinction coefficient regression equations for HC and WP smoke as functions of wavelength and RH. These are taken from Sutherland's work.[Sut83]

The value of α for HC in the mid-IR and far-IR is small; therefore, the code does not attempt to predict the very large number of HC munitions required in these spectral regions.

1.3 Meteorological Parameters

The rate of smoke cloud expansion, and thus the concentration of smoke within the cloud, is very sensitive to the Pasquill stability category. KWIK allows the user to specify this category or to compute it based on fundamental inputs of windspeed (required for the cloud diffusion calculations), date, time of day, latitude, longitude, cloud height, and cloud amount. Details of the Pasquill stability category determination are not given here, but are contained in other appropriate sources. [Smi73, PnCH86, Pas74, Tur64, Woo72]

The yield factor for hygroscopic smokes is dependent on R_H. The user may specify the R_H or have the model compute it from the air temperature t_a and dew-point temperature t_d (degrees Celsius):

$$R_H = 100(E_1/E_0)(\text{percent}), \tag{1.3}$$

$$E_1 = 10[AT_{\text{dp}}/(B + T_{\text{dp}})], \tag{1.4}$$

$$E_0 = 10[AT_{\text{air}}/(B + T_{\text{air}})], \tag{1.5}$$

where for the relevant value of T, A is 9.5 for negative T or 7.5 for positive T, and B is 265.5 for negative T or 237.3 for positive T.

The windspeed and wind direction are required for the cloud transport and diffusion calculations. Visibility is required if adverse weather corrections are specified. An option is included to use climatological data from the EOSAEL CLIMAT routine.

1.4 Smoke Source Characteristics

Table 1.1 presents the munition source characteristics for the eight munitions in KWIK.

The yield factors for HC and WP smokes, respectively, are determined from the parameterizations:

$$\begin{aligned} YF(\text{for HC}) = 1.1321144 - 3.71356073 \times 10^{-2} R_H + \\ 1.14309537 \times 10^{-2} R_H^2 - 6.76622133 \times 10^{-4} R_H^3 \\ +1.66489033 \times 10^{-5} R_H^4 - 1.82895831 \times 10^{-7} R_H^5 \\ +7.46031366 \times 10^{-10} R_H^6, \\ \\ \text{and} \\ YF(\text{for WP}) = 2.8407822 + 6.06607505 \times 10^{-3} R_H + \\ 6.16250212 \times 10^{-3} R_H^2 - 3.92696251 \times 10^{-4} R_H^3 \\ +9.96417905 \times 10^{-6} R_H^4 - 1.10946221 \times 10^{-7} R_H^5 \\ +4.56350757 \times 10^{-10} R_H^6, \end{aligned}$$

(1.6)

(1.7)

where R_H, the relative humidity, is in percent.

1.5 Surface Roughness

The surface roughness estimate is an implicit part of any diffusion or smoke obscuration model. Topography, or the configuration of an area or region of the earth's surface, is typically described in terms of roughness elements, roughness lengths, or land-use categories.[Han85]

The average roughness element for a particular region can be used to calculate the surface length, z_0, using a logrithmic relationship. However, the KWIK model now uses the land-use category method shown in table 3. This method is very simple and useful for estimating z_0. The word picture descriptions of land use shown in table 3 are used to select the appropriate input value of roughness length for the model. Note that the table includes terrain features, such as hills and mountains, that constitute a drag contribution to surface roughness. Roughness lengths for such complex terrains are much larger than the typical vegetative canopy would suggest.

Table 1.3: LAND-USE CATEGORIES ASSOCIATED WITH ROUGHNESS LENGTH(z_0)

Type of Surface	z_0 Meters
Farmland	
Natural snow surface (farmland)	0.003
Long grass (0.6 m),crops	0.05
Few trees, summer	0.07
Hedge rows	0.10
Trees, hedges, few buildings	0.20
Orchards, summer	2.00
Forest, wodded areas	
Subtropical Savannah, scattered trees	0.25
Fairly level wooded country	0.30
Forest clearings, cutover areas	0.40
Fairly level coniferous, 15 to 29 m trees	1.10
Rolling terrain, $\sim 20m$ trees	2.00
Forested ridges, hills	3.50
Mountains, unforested	
Rolling hills, low mountains	0.75
Plains	
Fairly level grass, few trees, winter	0.01
Fairly level grass, few trees, summer	0.02
Uncut grass, isolated trees	0.03
Brush, scrub growth, open	0.15
Brush, scrub growth, dense	0.25
Residential, industrial	
Villages, small towns	0.60
Mixed trees, fields, residential and industrial structures	2.50

1.6 Diffusion

The KWIK model assumes Gaussian diffusion, but with a modified form to account for non-Gaussian aspects of continuous sources. The resulting crosswind integrated path concentration ($CWIC$) is [PnCH86]

$$x_{CWIC} = (2/\pi)^{1/2} \frac{Q}{\bar{V}\sigma_Z} \exp\{-1/2[(z-h)/\sigma_Z]^{3/2}\}, \tag{1.8}$$

where

Q = source strength in grams per second

$\bar{V}$ = windspeed in meters per second

σ_Z = vertical diffusion sigma (meters)

z = height of the LOS (meters)

h = height of the cloud centroid (meters)

X_{CWIC} = CL or path integrated concentration (grams per meters^2)

The vertical dispersion length σ_Z is further parameterized according to the Pasquill power law

$$\sigma_Z = cx^d, \tag{1.9}$$

where x is the downwind distance of the cloud centroid (meters).

The values of c and d are computed from

$$c = S_{i1} + S_{i2}z_0 - S_{i3}z_0^2, \tag{1.10}$$

$$d = D_{i1} + D_{i2}z_0 + D_{i3}z_0^2, \tag{1.11}$$

where i is the index of the Pasquill category (1 to 6 for A to F). Values for these 6 by 3 matrices for S and D are contained in the computer code under those variable names. Regression equations for c and d, including values for C and D, are given in table C-3.[?] The user inputs values for z_0 from table 3. Because of the nature of equation (10), c may become negative for certain values of z_0, which is dependent upon the atmospheric stability category. Because this condition would cause problems with equations (12) and (13), the user must adjust values of z_0 (from table 3) greater than 1.5 m, depending on the stability category as follows: Category A, 1.5 m; categories D and F, 1.6 m; and categories B and C , 1.7 m. By averaging over the exponential in equation (8) at several downwind distances and for all Pasquill categories, the compact form for the downwind length over which the smoke is effective is expressed as

$$x = \left[\frac{0.731Q}{c\bar{V}x_{CWIC}}\right]^{1/d}. \tag{1.12}$$

This equation is used to determine the munition spacing required for HC continuous sources. The source strength Q has been adjusted for the munition efficiency (0.7) and yield factor, equation (6). For quasi-instantaneous WP smoke, the diffusion is assumed to be the usual Gaussian puff equation.

$$x_{CWIC} = \frac{Q_T}{\pi\sigma_{xi}\sigma_{zi}} \exp\left\{-1/2\left[\left(\frac{x-\bar{V}t}{\sigma_{xi}}\right)^2 + \left(\frac{\bar{Z}-z}{\sigma_{zi}}\right)^2\right]\right\}, \tag{1.13}$$

where Q_T is the unit total release per 100 m times the WP yeild factor, equation (7), and the puff height centroid $\bar{Z}$ is the buoyan rise due to the exothermic character of WP and is assumed to vary partly because of increasing windspeed with height. The dispersion parameters σ_{xi} and σ_{zi} are given by

$$\sigma_{xi} = \sigma_{x0} + 0.74ax^b, \tag{1.14}$$

and

$$\sigma_{zi} = \sigma_{z0} + 0.667cx^d, \tag{1.15}$$

where σ_{x0}, σ_{z0} are the source sigmas for WP, c, d are the parameters of equations (10) and (11), a is dependent on Pasquill category (0.4, 0.32, 0.22, 0.144, 0.102, and 0.076 for categories A through F, respectively), and b is 0.9. The exponential term is average over downwind distances, Pasquill category , and centroid heights to provide a KWIK for WP over the 100-m source distance:

$$x_{CWIC} = \frac{0.0181Q_T}{\pi\sigma_{xi}\sigma_{zi}}. \tag{1.16}$$

Munition placement separations for WP are then calculated as

$$x = 100\frac{x_{CWIC}}{CL} \tag{1.17}$$

for visible and near-IR screening. Because of the greater amount of smoke required for screening in the mid- and far-IR, the separation of WP munitions is fixed at the maximum distance of 60m, and the number of WP munitions per 60-m intervals is calculated as

$$N = \frac{B_d}{100}\frac{CL}{x_{CWIC}}, \tag{1.18}$$

where B_d is the nominal burst diameter from table 1.

1.7 Munition Expenditures

The required number and placement of munitions are based on the HC munition spaing, equation (12); WP munition spacing, equations (16) and (17) for visible and near-IR screening; and number of WP munitions per screen length, equation (18), for mid- and far-IR screening. For HC munitions, the required CL in equation (2) replaces x_{CWIC}in equation (12), and the effective downwind length is adjusted for the angle between the line of sight (LOS) and the wind direction by the factor δ as,

$$x' = \delta^{-1}x \tag{1.19}$$

where

$$\delta = [13.69/(13.69\sin^2\theta + \cos^2\theta)]^{1/2}, \tag{1.20}$$

and θ is the angle between the LOS and wind direction. Thus, less smoke is required for and LOS that passes more obliquely through the screen. The KWIK algorithm calculates the initial and sustaining volleys required to establish and maintain a smoke screen for a desired time and length. KWIK also calculates the shell separations for initial and sustaining volleys. Other calculations include the rate of fire, the upwind adjustment point, and the total munition expenditures required for a particular mission.

1.7.1 Correction for Upwind Adjustment Distances

The angle $\hat{A}$ between the wind direction and the LOS, which determines whether the wind is cross, quarter, head, or tail, is used to determine the upwind adjustment factor, f_c, as follows:

Quartering wind ($22.5 < \hat{A} < 67.5$ or $112.5 < \hat{A} > 157.5$) or

Head wind or Tail wind ($\hat{A} < 22.5$ or $\hat{A} < 157.5$);

$f_c = 0.5$;

Crosswind ($67.5 < \hat{A} < 112.5$)

$f_c = 1$.

If $\hat{A}$ is greater than 180°, $\hat{A}$ - 180 is used in place of $\hat{A}$ for determining f_c, which is used as a correction factor for all WP or HC munitions.

1.7.2 HC Munitions

The rate of fire (R_{hc}) for HC munitions is based on the nominal burn time of the munition, that is, 120 s, or R_{hc}= 0.5 rounds per minute.

The determination of the number of HC rounds required for the initial volley is made from

$$V_i = \frac{SL + U_{hc}}{X_i}, \tag{1.21}$$

where SL represents the desired screen length and X_i, the initial impact separation, is equal to 45 $\bar{V}$. The number of rounds for sustaining volleys is determined from

$$V_s = \frac{SL + U_{hc}}{x}, \tag{1.22}$$

where x is downwind travel distance from equation (12).

An upwind adjustment distance, U_{hc}, has been included in the model to allow or the time and space required for proper smoke buildup before it reaches the initial screening point. This adjustment point is the site where the initial smoke round is placed, x meters upwind of the area to be screened. For HC smoke, the upwind adjustment distance is given by

$$U_{hc} = f_c X_i. \tag{1.23}$$

The following is also considered: If the initial impact separation, X_i , is greater than the sustaining impact separation, x, the initial, and hence U_{hc} also, is set equal to the sustaining shell spacing. The total munition expenditure (M_{hc}) for an HC smoke source in the visible or near-IR wavelength is then determined from

$$M_{hc} = V_i + V_s(R_{hc}T_s - 1), \tag{1.24}$$

where T_s is the total desired screen time in minutes.

1.7.3 WP Bulk Munitions

Fire Interval.

The fire interval between volleys, T_R(in seconds), for visible and near-IR wavelengths is given by

$$T_R = \frac{x + B_d}{\bar{V}}, \tag{1.25}$$

where x is the small impact separation computed from equation (15), and B_d is the nominal burst diameter from table 1. For mid- and far-IR wavelengths, T_R is given by

$$T_R = \frac{2B_d}{\bar{V}}. \tag{1.26}$$

The value of T_R is rounded off to the nearest 20 s and then converted to minutes. This time interval is related to the maximum rate of fire of the howitzers.

The actual rate of fire (R_f), in rounds per minute, is the reciprocal of T_R. For E and F stability categories (stable flow), table 4 shows the respective rates of fire for different weapons. The KWIK algorithm contains the following exceptions to equation (25) for M110 WP munition:

Table 1.4: RATE OF FIRE UNDER STABLE ATMOSPHERIC CONDITIONS (E AND F CATEGORIES) FOR WP (BULK) SOURCES

Weapon	Rate of fire (rounds/min)
105-mm howitzer	2
155-mm howitzer	1
81-mm mortar	4
4.2-in mortar	2

- For visible wavelengths, crosswind case, stability category c (windspeed $< 3m/s$); $T_R = 40s$.
- For near-IR wavelength, crosswind case, stability categories A and B (windspeed $< 3m/s$); RH > 79; $T_R = 60s$.
- For near-IR wavelength, crosswind case, stability catagories E and F , $T_R = 40s$.

Equations (25) and (26) are also used to calculate the rate of fire for WP mortars with the following limits: The minimum rate of fire is one round per minute, and the maximum rate is three or eight rounds per minute, respectively, for 4.2-in or 81-mm mortars.

Initial and Sustaining Volleys

The number of initial and sustaining rounds for all WP bulk munitions for visible and near-IR wavelengths is determined from

$$V = \frac{SL + U_{wp}}{x}. \tag{1.27}$$

However, if the screen length, SL, is less than the downwind travel distance x, the latter takes the value of SL.

For mid- and far-IR wavelengths, the following expression is used:

$$V = \frac{B_d CL}{x_{CWIC}} \frac{1}{100}, \tag{1.28}$$

where CL is defined in equation (2) and x_{CWIC} in equation (8).

The WP upwind adjustment distance depends on the windspeed and is given by

$$U_{wp} = 30\bar{V} f_c, \tag{1.29}$$

which allows $30s$ for the required effective buildup time. The maximum value of U_{wp} is the smaller of either the impact separation x (from equation (17)) or the screen length SL. For mid- and far-IR wavelengths,U_{hp} is 60m, which is approximately the burst diameter. f_c is the upwind adjustment factor, as discussed in section 1.7.1.

These values are derived from field trial experience.[?]

Recalculated Impact Separations.

For atmospheric stability categories of neutral and unstable, the impact separation for all wavelengths is recalculated as follows:

for C and D categories,

$$X_r = \frac{SL + U_{wp}}{V+1}; \tag{1.30}$$

$$\tag{1.31}$$

for A and B catagories,

$$X_r = \frac{SL + U_{wp}}{V+2}. \tag{1.32}$$

The upwind adjustment value for visible and near-IR wavelengths is then readjusted only if U_{wp} is greater than the recomputed X_r. In that case, U_{wp} set equal to X_r.

The expressions for the total number of WP munitions for visible and near- IR and mid- and far-IR are shown, respectively, in equations (32) and (33).

$$M_{vn} = (T_S R_f - 1)V + V, \tag{1.33}$$

and

$$M_{mf} = (T_S R_f - 1)(\frac{SL}{B_d} + 1)V, \tag{1.34}$$

For E or F atmospheric stability conditions, equation (27) is also used for visible and near-IR wavelengths with the corresponding rate of fire (Rf) from table 4.

1.8 WP and RP Area Source Munitions

The M825 and M819 are area-source munitions that produce semicontinuous smoke plumes similar to HC sources[MM84]. The required impact separations for these munitions are calculated from equation(34), where t is set less than the total burn time (612 s), say 500 s (for M825), and solved for$x$.

$$x_{CWIC} = \frac{K\lambda\Omega\Delta x Q(t)}{D\bar{V}cx^d}\sum_n L_n[n^{1-d} - (n-1)^{1-d}], \tag{1.35}$$

where $Q(t)$ is a time-dependent function expressed as

$$Q(t) = \frac{M}{T_b}\left[B_1 + B_2\left(\frac{t}{T_b}\right) + B_3\left(\frac{t}{T_b}\right)^2 + B_4\left(\frac{t}{T_b}\right)^3\right] + B_5 B_6 e^{-B_6 t}. \tag{1.36}$$

All terms in equations (34) and (35) are defined in table 5. The diameter of the munition footprint area, d_f, is defined as

$$d_f = 2\sqrt{D/\pi} \tag{1.37}$$

where D is the footprint area of the source from table 5.

The area source portion of KWIK provides calculations for shell spacings, firing interval, upwind adjustment point, and munition expenditures for a given screen level, duration, and spectral band to be obscured. Figure 1 shows the procedure used for these computations. The two major branches of the flowchart are dependent on whether $x(x,t)$ is less than or greater than or equal to 1.1 CL (10 percent safety factor).

Also, the stability-dependent value of c is adjusted to $0.698/\bar{V}$ for stability category A. This adjustment is done to prevent the windspeed dependency for a very unstable atmosphere when calculating $x(x,t)$ in equation (34).

Table 1.5: AREA SOURCE PARAMETERS

Parameter	M825	M819
K (normalization constant)	2.08	8.65
λ (munition efficiency)	0.74	0.48
Δx (area increment width) meters	18.4	8.17
Ω (humidity yield factor) calculated from empirical polynomials		
D(footprint area) meters squared	9503	1885
$\bar{V}$ (windspeed) meters per second	variable	variable
c (stability category coefficient)	variable[Han79]	
d (stability category index)	variable[Han79]	
L_n (area increment lengths) meters	55.16 94.21 108.03	24.6 42.0 48.1
x (downwind distance) meters	variable	variable
t (time) seconds	variable	variable
M (munition fill weight) grams	7451	1285.5
T_b(total burn duration) seconds	600	240
B_1 (burn function coefficient)	3.326	5.088
B_2 (burn function coefficient)	-9.4664	-20.26
B_3 (burn function coefficient)	9.5994	25.938
B_4 (burn function coefficient)	-3.1612	-10.4
B_5 (burn function coefficient)	0.0	0.0
B_6 (burn function coefficient)	0.0	0.0

Table 1.6: WIND CORRECTION FACTOR

Wind Direction	Range (deg)	W_{cf}(rad)
Head	< 30 or > 330	0.0
Tail	> 150 and < 210	π
Cross	$> = 60$ and $< = 120$	$\pi/2$
Cross	> 240 and $< = 300$	$\pi/2$
Quarter	remaining angles	$\pi/4$

1.8.1 Wind Direction Correction Factor

$$W_{cf} = abs(WD - LOS), \tag{1.38}$$

The above expression is basic to both branches of the flowchart (see figure 1). Equation (37) represents the absolute value of the difference between the wind direction, WD, and the angle of the LOS with magnetic north.

Table 6 shows the different W_{cf} values used for head wind, tail wind, crosswind, and quartering wind.

1.8.2 Upwind Adjustment Point

The upwind adjustment point for area source munitions is dependent upon wind direction. The wind direction correction factor, W_{cf}, is converted to degrees and used to determine an upwind adjustment factor U_f. This factor is set equal to 0.5, except in case of a crosswind, when it is set equal to 1.0. The upwind adjustment point is then calculated for the M825 and the M819 munitions, respectively, by

$$U_{M825} = 110U_f, \tag{1.39}$$

and

$$U_{M819} = 50U_f. \tag{1.40}$$

1.8.3 Overlapping Footprint Case

If $x < 1.1CL$, overlapping footprints are required, and the basic shell spacing is calculated from

$$S = d_f \frac{x(x,t)}{1.1CL}, \tag{1.41}$$

where $x(x,t)$ is calculated from equation (32) for $X = 20m$ and $t = 100s$ for M825 munition and $x = 20m$ and $t = 40s$ for M819 munition.

The number of rounds required for the initial volley is

$$V_i = Int\left(\frac{SL + U}{S} + 0.95\right), \tag{1.42}$$

where Int is the integer value of the quantity in parenthesis, SL represents the described screen length in meters, and U is an upwind distance for the particular munition as given by equations (38) and (39).

Initial Volley Adjustment

The initial volley is adjusted depending on wind direction and atmospheric stability as shown in tables 7 and 8.

Table 1.7: INITIAL VOLLEY ADJUSTMENT FOR HEAD WIND/TAIL WIND

Stability Category	Rounds Added
A and B	3
C	2
D	1
F	-1 (for $V_i > 2$ only)

Table 1.8: INITIAL VOLLEY ADJUSTMENT FOR QUARTERING AND CROSSWIND

Stability Category	Rounds Added
A and B	2
C and D	1

Total Sustaining Volleys

The total number of rounds required for the sustaining volleys is

$$V_{ts} = V_i Int\left(\frac{T_S}{T_R} - 0.05\right), \tag{1.43}$$

where T_S is the screen time in S, V_i is from equation (55), and T_R is 100 s for the M825 and 40 s for the M819 munition.

Fire Interval

The maximum fire interval for the M825 is 300 s and 240 s for the M819. For high wind ($> 5m = s$) cases as head wind/tail wind situations, the sustaining fire intervals for the M825 are given in table 9. The rates in this table are also valid for nonoverlapping cases. *5-min intervals, except as shown.

Single Sustaining Volley

The number of sustaining volleys is given by

$$N_{sv} = Int\left(\frac{T_s}{RF} + 0.5\right) - 1, \tag{1.44}$$

while the number of rounds for a single sustaining volley is

$$V_{ss} = Int\left(\frac{V_s}{N_{sv}} + 0.5\right). \tag{1.45}$$

Table 1.9: KWIK WP M825 MUNITION FIRE INTERVALS (MIN)*

Wavelength Band	Crosswind $> 5m/s$	Head/Tail Wind $> 5m/s$	Head/Tail Wind $< 5m/s$
Visible	2.5	1.5	2.0
Near-IR	1.5	1.0	2.0

Table 1.10: WIND ORIENTATION CONSTANT K

Wind Direction	K (M825)	K (M819)
Cross	110	50
Quarting	55	25
Head	0	0
Tail	0	0

Shell Spacings

The initial shell spacing for all wind situations is given by

$$S_i = \frac{(SL + K)}{V_i}, \tag{1.46}$$

where K is a constant depending on the wind direction, as indicated in table 10 for M825 and M819.

The sustaining shell spacing, where required, is calculated by

$$S_s = \frac{(SL + K)}{V_{ss}}, \tag{1.47}$$

where all terms are as defined previously.

1.8.4 Nonoverlapping Footprints

If $x > 1.1, CLx$ is equal to $1.1CL$ and the basic shell spacing S is calculated from

$$S = X(t) + d_f, \tag{1.48}$$

where d_f is defined in equation (36), and $X(t)$ is calculated from M825 between 100 and 500 s at 100-s intervals and between 40 and 200 s at 20-s intervals for M819. S is tested against the maximum allowable distance

$$S_{max} = 45\bar{V} + d_f, \tag{1.49}$$

where $\bar{V}$ is the windspeed in meters per second. The minimum number of munitions for the longest time is determined, and values of $X(t), T$ and S_{min}, corresponding to this minimum expenditure of munitions, are used to obtain the shell spacing and firing interval.

Initial Volley

The initial volley, V_i, is calculated from equation (41), except that S_{min} is used for S. The same initial volley adjustments as given for the overlapping case are applied for the nonoverlapping case, according to tables 7 and 8.

Sustaining Volley

The total sustaining volley is defined by

$$V_{ts} = Int\left(\frac{SL + K}{S} + 0.95\right) Int\left(\frac{T_s}{T} - 0.05\right), \tag{1.50}$$

where S is from equation (47) and T is the time, in seconds, calculated for the least munitions, as mentioned in section 1.8.4.

Fire Interval

The sustaining fire interval is computed from

$$RF = Int\left(\frac{T_s}{I}\right), \tag{1.51}$$

where Int is the integer value of T_s/I, and

$$I = Int\left(\frac{V_i + V_{ts}}{V_i}\right). \tag{1.52}$$

The initial and sustaining shell spacing calculations for the nonoverlapping footprint case are the same as those given in equations (45) and (46).

Total Rounds

The total number of rounds required for all cases is given by

$$R_T = N_{SV} V_{SS} + V_i. \tag{1.53}$$

The area source calculations discussed in sections 1.8.4.1 to 1.8.4.4 are shown in figure 1 for M825 and M819 munitions.

1.9 Model Validation and Improvements

During Smoke Week VII trials conducted at Fort Sill, Oklahoma, during July 1985, the FM 6-40 munition expenditures tables were compared with munition predictions obtained from KWIK model calculations. Live-fired M825 WP (wedge), M110 WP (bulk), and M116 HC munitions were used. However, only the M825 munitions provided a valid comparison with the FM 6-40 tables. The following conclusions were derived from the test data analysis:

- The present FM 6-40 munition tables are not consistent in determining munition expenditures. About 45 percent of the comparison trials were underpredicted in both duration and length, while at least 18 percent were overpredicted.
- The KWIK model provided more consistent munition predictions; however, it underpredicted, in screen length only, in about 45 percent of the comparison trials.
- Considering the above conclusions, KWIK achieved better results with 40-percent fewer munitions than the FM 6-40 tables.[PnCH86]

Based on Smoke Week VII data, several improvements have been made to the model, including changing the threshold transmittance levels. For visible and near-IR wavelengths the threshold was changed from 0.05 to 0.10. For mid- and far-IR wavelengths the threshold was changed from 0.02 to 0.05. The basis for this change is shown in figure 2, which is a comparison between 5- and 10-percent transmission low visibility infrared (LOVIR) transmissiometry levels and PRESTO (Personal Response Evaluation System for Target Obscuration) data for several M825 munition trials.

Another improvement to KWIK has to do with the sustaining fire intervals (table 9). These intervals were derived by using the COMBIC model to determine if a particular fire interval would sustain a smoke screen for the desired length and time and for a determined transmittance threshold level.[APn87] enddocument

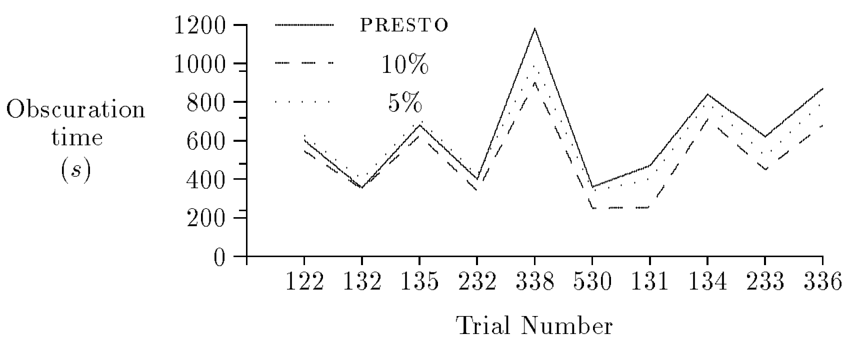
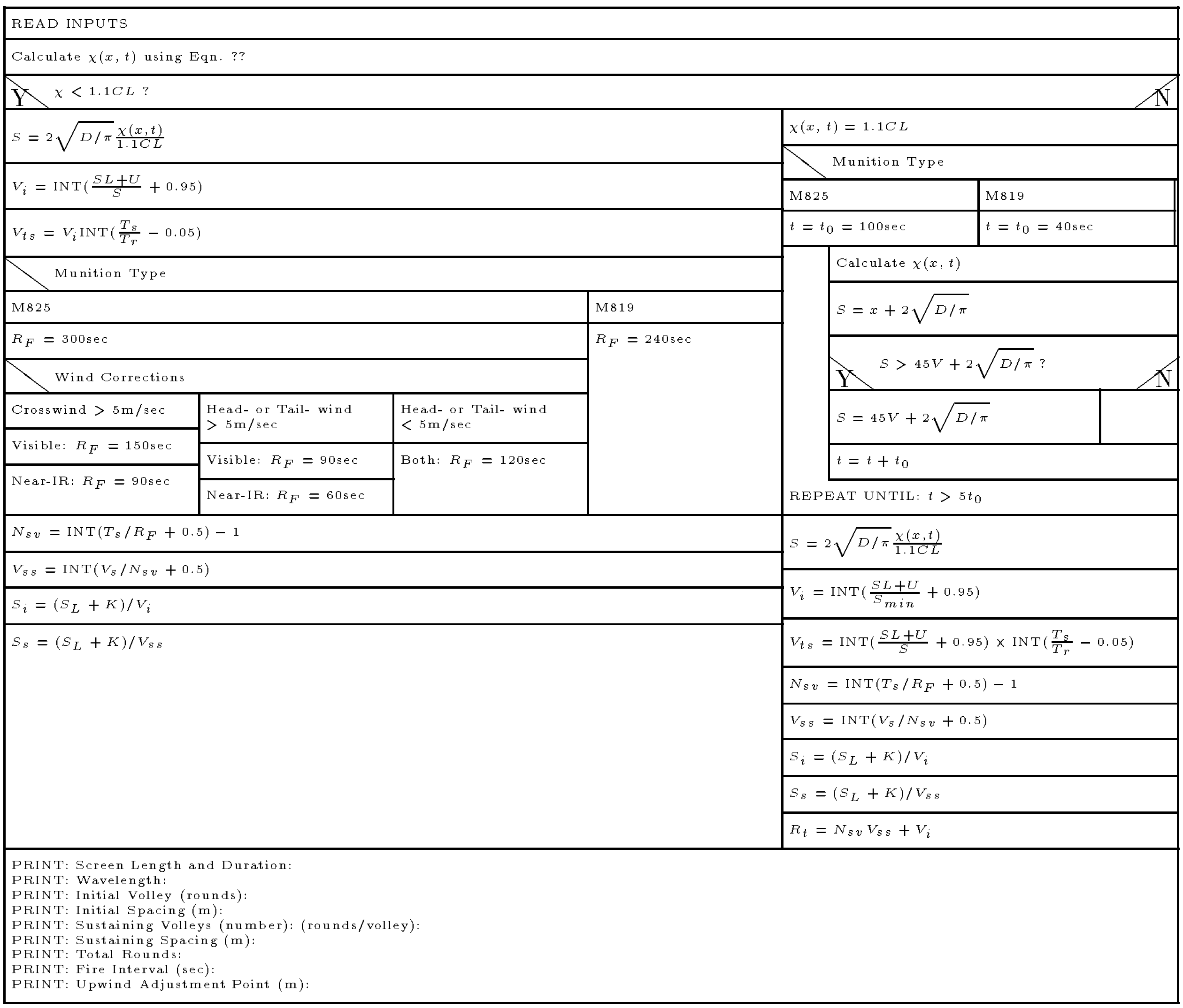


Figure 1.1: Comparison between 5- and 10- percent transmission levels LOVIR and PRESTO obscuration for several M825 trials.

Figure 1.2: Flowchart of area source calculations for M825 and M819 munitions.

KWIK — Nassi-Schneiderman Diagram



Chapter 2

USER'S GUIDE

2.1 KWIK Module

KWIK contains the subroutines KWIK,KWIK1, KWIK2,KWIK3,KWIK4,KWIK5, and KWIK6 that are described below. Function JPASCT, which converts the interger code for Pasquill category to an alpha character, and the XSCALE model are called by KWIK. The XSCALE[Dun82] module determines the transmittance through natural aerosols (haze, fog, rain, and snow) for both individual wavelengths and broadband averages in the range of 0.2 to 12.6 μm for arbitrary slant paths.

KWIK must be compiled with XSCALE and EOEXEC[Mas87] modules. The executive routine EOEXEC is the controller for EOSAEL87. EOEXEC reads input common to the various modules (for example, wavelength); determines associated options, such as, climatological data; and establishes the general flow of programs execution.

KWIK module calculates the: (1) projectile impact separation, (2) number of rounds, (3) total expenditures, and (4) rate of fire required to form and maintain a chemical-smoke screen of desired length and time duration. The calculation is performed for inventory 155- and 105-mm WP and HC munitions. Output is for visible and near-IR obscuration, for both WP and HC, and for mid- and far-IR wavelengths for WP. The threshold transmittance that is used in the obscuration criteria is default values given by KWIK. Account is taken of the range to target and the angle of the LOS through the screen.

The total transmittance threshold required is a combination of the natural obscuration present caused by adverse weather (haze, fog, rain, or snow)

2.1.1 Input for the KWIK Module

Meteorological inputs are required for the KWIK modeled atmospheric diffusion computation, which is based on a Gaussian cloud with expansion parameters dependent on Pasquill category and surface roughness. Pasquill category and RH, required to adjust for the hygroscopic property of the smoke, may optionally be computed in KWIK from fundamental meteorological inputs, time of day, and site location. Meteorological requirements can be met by either user specifications (see table 11) or through the EOSAEL climatology module CLIMAT.

Input to KWIK is on standardized records containing an identifier in columns 1 to 4 followed by up to 7 values in 10-column fields beginning in column 11, FORMAT (A4,6X,7E10.4). All input parameters are real (that is, decimal) values. The order of input records is immaterial except for the DONE record, which must be last. Table 11 describes the input records for KWIK as well as the order the parameters on each record must follow.

If CLIMAT data are used, ICLMAT in EOEXEC must be set to a nonzero value. Meteorological requirements of KWIK are then transferred through common block CLYMAT. In such a case, it will be impossible to input additional meteorological data interval to the KWIK module if KWIK is being cycled (run for more than

Table 2.1: The SCRN Card. Screen and LOS definition (required)

```
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
SCRN            TIME      XO        H3       AST       DLS       TRL       FOG
```

NAME	UNITS	Description
TIME	min.	Screen Duration
XO	m	Screen Length
H3	km	Slant range observer to target
AST	$(x)^\circ$	Elevation angle of target from the observer with respect to the horizontal (degrees)
DLS	$(x)^\circ$	Azimuth (angle clockwise with respect to north in degrees) of the LOS
TRL	m	Terrain roughness length
FOG		Adverse weather or haze correction = 0. No adverse weather correction = 1. Correct for visibility at visible wavelength only = 2. Correct for fog or haze for maritime (artic and polar) air mass = 3. Correct for fog or haze for maritime urban air mass = 4. Correct for fog or haze for rural (continental polar) air mass = 5. Correct for fog one (heavy advection) = 6. Correct for fog two (moderate radiation) = 7. Correct for rain (drizzle) = 8. Correct for rain (widespread) = 9. Correct for rain (thunderstorm) = 10. Correct for snow

Table 2.2: The METR Card. Meteorological Inputs - not required if ICCMAT nonzero.

```
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
METR              S3        DO      PCAT        VS        RO        TO        T1
```

NAME	UNITS	Description
S3	m/s	Windspeed
DO	$(x)^\circ$	Wind direction (usual met convention, degrees clockwise from north from which wind originates)
PCAT		Pasquill category. 1 = A, 2 = B, 3 = C, 4 = D, 5 = E, 6 = F. If input as 0, then PASQ record required.
VS	km	Visibility ignored if FOG is 0 on SCRN record
RO	%	Relative humidity. If input as 0, then temperature and dew point below are required.
TO	$(x)^\circ$C	Air temperature, required only if RO input as 0
T1	$(x)^\circ$C	Dew-point temperature required only if RO input as 0.

Table 2.3: The PASQ Card. Pasquill category calculation

```
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
PASQ            SLAT      SLONG     SJDATE    SZHOUR        CO        C1
```

NAME	UNITS	Description
SLAT	$(x)^\circ$	Latitude of site, Positive is north latitude
SLONG	$(x)^\circ$	Logitude of site, Positive is east logitude
SJDATE		Julian date (decimal days from beginning of year)
SZHOUR		GMT time of day (decimal and fractional hours)
CO	m	Ceilling cloud height
C1	%	Cloud cover

Table 2.4: The MUNI Card. Munition determination

```
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
MUNI             MUN        GO      DONE
```

NAME	UNITS	Description
MUN		Type of munition; 1 = 105-/155-mm howitzer, 2 = 81-mm/4.2-in mortars,3 = 155-mm M825 howitzer, 4 = 81-mm M819 mortar
GO		End of this set of inputs; execute and then read next set
DONE		Executive record - required as last input for return of control to the KWIK executive subroutine

data set). User records are input on unit IOIN and listings output to unit IOOUT. These unit numbers are provided by common block IOUNIT. In addition, common block CONST contains mathematical constants. The GEOMET common block transfers geometrical data entered through EOEXEC. If IGEOSW=1, then target and observer range are computed.

2.1.2 Subroutines

KWIK contains seven subroutines:KWIK,KWIK1, KWIK2,KWIK3,KWIK4,KWIK5, andKWIK6.

KWIK. This subroutine (1) performs all input and output for the module; (2) performs the correction for adverse weather; (3) computes RH from temperature and dew point, depending in options chosen; and (4) calls the other subroutines of the module. User input records are read and appropriate calls to the EOSAEL XSCALE routine are made if adverse weather corrections are desired.

If the Pasquill category is not used as a input, the subroutine KWIK1 is called to compute it. The subroutineKWIK2 computes the yield factor, coefficients, and indicates for the power law orthogonal dispersion parameters used in computing the KWIK for HC and WP smoke. KWIK3 first computes the crosswind integrated concentration for WP smoke and then calculates the required munition expenditures for 81-mm and 4.2-in mortars. KWIK4 performs the same operations asKWIK3 for 105- and 155-mm howitzers by using HC and WP munitions. KWIK5 provides the necessary computer code to print out the results calculated inKWIK3 for 81-mm and 4.2-in mortars. KWIK6 calculates munition expenditures for M825 and M819 munitions.

KWIK1. This subroutine computes Pasquill category based on windspeed, cloud cover, cloud height and site location, and time of day for computation of solar isolation. The category is returned in variable IPO as the numbers 1 through 6, corresponding to Pasquill categories A through F.

KWIK2. This subroutine uses Pasquill category and terrain roughness length to determine the cloud vertical and crosswind expansion rates. The yield factor is computed for each smoke type, and the crosswind integrated concentration is computed based on cloud dimension and correction for the angle between the LOS and the wind direction.

KWIK3. This routine computes the munitions required to produce and maintain the smoke screed for 81-mm and 4.2-in mortars. The number of guns required is based on the ratio of the total smoke mass, corrected for the hygroscopic yield factor, to the amount of smoke available in one munition. Based on the burn duration of the smoke munition and the time required for smoke buildup, the rate of fire is computed. From the total time required for a smoke screen, the total number of munitions that must be used is computed. Shell spacing is dependent on the downwind expansion of the cloud.

KWIK4. This routine performs the same function asKWIK3, but for 105- and 155-mm howitzers.

KWIK5. This routine provides an output listing of the munition expenditure calculations for 81-mm and 4,2-in mortars.

KWIK6. This routine provides the area sources calculations for munition expenditures of the M825 (155-mm howitzer) and M819(81-mm mortar) munitions. KWIK6 performs the same operations asKWIK3 and also lists the output calculations for these munitions.

2.2 Examples of Use

The following pages show samples of input and output data. The first two card images "WAVL 1.06 1.06" and "KWIK" are required by the EOEXEC program, which is the driver for EOSAEL87. The EOEXEC program is described in EOSAEL87, Volume 2.[Mas87] The remaining card image starts with an identifier, such as SCRN, METR, PASQ, or MUNI. The latter identifies the munition type. The identifier GO is used between multiple data sets. After the last data set, the run must contain the DONE, END and STOP identifiers. Further description of these identifiers and data within each card image is given in table 11.

The sample of the output data corresponds to the input data for M825 and M819 smoke munitions.

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