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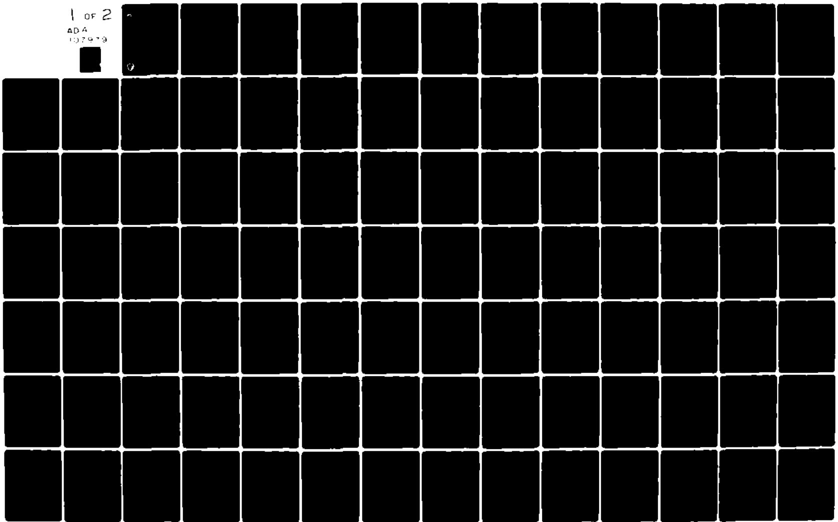

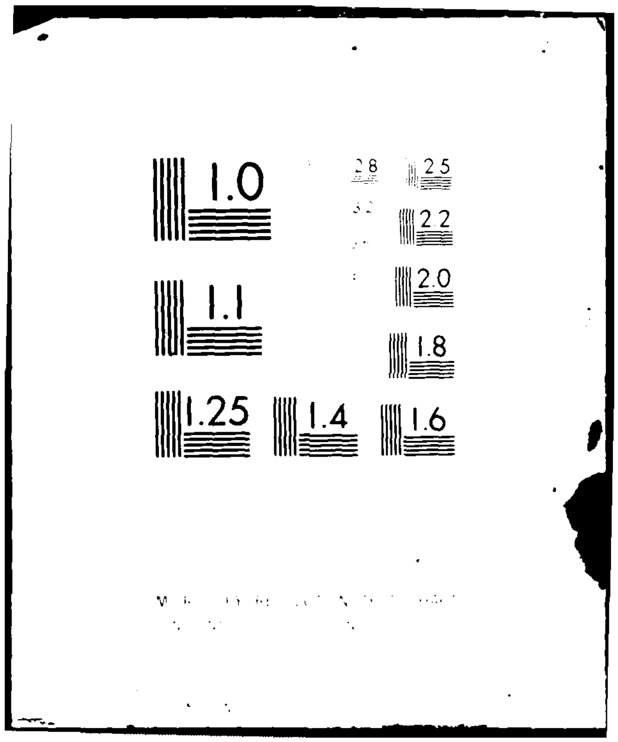
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AN OBJECTIVE SUMMARY OF US ARMY ELECTRO-OPTICAL MODELING AND FIELD TESTING IN AN OBSCURING ENVIRONMENT

OCTOBER 1981

By

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ERRATA SHEET

Footnote 51, page 20, and Reference 51, page 43, should read
"Revision to the Smoke Effectiveness Manual Model (SEMM)," 1980, Interim Note F-39, Field Equipment and Technology Division, US Army Materiel Systems Analyses Activity, Aberdeen Proving Ground, MD

Definition 5.2, page 74, should read
Usually the military nomenclature and a qualitative description of the delivery system, accompanied by quantitative data....

The four methodology options listed under 6.11, page 76, should read
Sutton-Calder
Pennsyle model
Sloop model
Cramer

The term being defined in 6.23, page 77, should read
INTEGRATION POINTS (INITIAL)....

The term being defined in 6.24, page 77, should read
INTEGRATION POINTS (MAXIMUM)....

REPORT DOCUMENTATION PAGE

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Fifteen electro-optical obscuration models in use within the Army are examined in terms of input and output requirements, and eighteen data bases from major Army obscuration effectiveness tests are examined and summarized. Tables showing side-by-side model data requirements and test measurements on hand are presented along with short descriptions of each model and test. The results are discussed in relation to strengths and deficiencies in current modeling and testing capabilities.

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1. INTRODUCTION

Since about 1972 several models have appeared in the Army literature addressing the problem of electro-optical (EO) obscuration in a realistic battlefield situation composed of an atmosphere of contaminants such as smoke, high explosive (HE) and vehicular dust, and fire products (that is, heat and smoke). Paralleling this effort have been a number of major tests primarily concerned with field performance of military EO systems but also used for obscuration model development.

This report presents a summation and evaluation of these research, development, and testing efforts by examining several model input and output requirements and comparing these requirements with measurements made in several major tests.

The major products of this report are short descriptions of the models and tests and comprehensive tables juxtapositioning model and data requirements with existent field test measurements. From these and other cited sources, some conclusions are drawn concerning the overall modeling and data deficiencies suggesting directions to be taken in the near future.

2. THE MODELS AND DATA SETS

2.1 Models

Fifteen Army obscuration models were selected for the study. Of the fifteen, six may be classified as general inventory smoke obscuration models (ACT I, ACT II, HECSOM, SOM II, SMOKE EOSAEL, AND GRNADE), one treats smoke produced by a burning tank (BURN), another treats fires in general (FIRE), four are inventory smoke munitions expenditure models (STILES, SEMM, KWIK, AND MUNXP), and three are artillery munition dust obscuration models (ASL DUST, DIRTRAN, AND HEDUST). The following paragraphs briefly describe the history, function, salient features, and scope of each model. Detailed descriptions of the models can be found in the references cited.

The ACT I Model[1] is based upon a revision of the Joint Technical Coordinating Group for munition effectiveness (JTCG/ME) Smoke Obscuration Model (SOM or SOM I) by the US Army Atmospheric Sciences Laboratory (ASL) which resulted in the computer code ASLSOM. The ASLSOM code was further modified by ASL, the Chemical Systems Laboratory (CSL), and the TRADOC Systems Analysis Activity (TRASANA) and resulted in the present version called ACT I.

The model is a general-purpose smoke obscuration model which addresses both instantaneous and semicontinuous burning inventory smoke munitions using the Gaussian formulation for cloud transport and diffusion. The problems of optical contrast and contrast transmittance are approached by way of first

[1]R. B. Gomez, R. Pennsyle, and D. Stadtlander, 1979, "Battlefield Obscuration Model, ACT I," Proceedings of Smoke Symposium III

principles in the single scattering approximation for cloud radiance calculations. The model treats general sensor-target scenarios which can include effects of external radiation sources such as sun and sky as well as artifical sources such as flares and lasers. The model uses routines developed from experiment by the Night Vision and Electro-Optics Laboratory (NVEOL)[2] to calculate target detection and recognition probabilities from computed contrast transmission and target illumination. The model also uses a Mie scattering routine (AGAUS)[3] to calculate smoke particle angular scattering functions. Atmospheric transmission (for adverse weather) is accounted for if extinction coefficient information is input.

The HECSOM Model[4] was developed by the H. E. Cramer (HEC) Company under contract to ASL and forms the basic transport and diffusion routine for the larger system called Experimental Prototype Automatic Meteorological Systems (EPAMS).

Except for minor coding differences, the optical routines of HECSOM are identical to those of ACT I. The model uses an expanded Gaussian approach to transport and diffusion which takes into account boundary and atmospheric scavenging effects on cloud dynamics. The model is unique in its approach for determining diffusion parameters from measured wind and temperature data. The model can be run independently, but certain of the inputs which would usually be obtained from other routines in the EPAMS system are not easily measured or estimated.

The SOM II Model[5 6] was developed for the JTCG/ME by the Lockheed Missile and Space Company, Incorporated, Huntsville Research and Engineering Center. The capabilities of the model are similar to those of ACT I and HECSOM although the computational options offered by SOM II make it somewhat distinct. The model allows one of four options for Gaussian type transport and

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[2]"Combat Simulation Target Acquisition Model and Data Input" (U), CONFIDENTIAL, 1980, Draft Technical Report, US Army Night Vision and Electro-Optics Laboratory, Fort Belvoir, VA (in process)

[3]A. Miller et al, 1978, Studies on the Development of Algorithms for the Prediction of Time Dependent Optical Properties of Aerosols, Contract Report under Contract DAAD07-78-C-0083, US Army Atmospheric Sciences Laboratory, White Sands Missile Range, NM

[4]R. K. Dumbauld and H. Bjorklund, 1977, Mixing Layer Analysis Routine and Transport/Diffusion Application Routine for EPAMS, ECOM-77-2, Atmospheric Sciences Laboratory, US Army Electronics Command, White Sands Missile Range, NM

[5]Smoke Obscuration Model II (SOM II) Computer Code Volume II - Analyst Manual, 1979, JTCG/ME Smoke and Aerosol Working Group Document 61 JTCG/ME-78-9-2

[6]Smoke Obscuration Model II (SOM II) Computer Code Volume I - Users Guide, 1979, JTCG/ME Smoke and Aerosol Working Group Document 61 JTCG/ME-78-9-1

diffusion which include those used in ACT I and HECSOM. For optical calculations of transmission for the ambient atmosphere, the SOM II code uses a modified version of the LOWTRAN[7] routine which includes provisions for using one of several "standard" atmospheres for the surroundings. Cloud optical calculations are based upon single scattering theory and differ only in detail from ACT I or HECSOM.

The SMOKE (EOSAEL) Model[8,9] is based upon a study by R. Zirkind of the General Research Corporation[10] under contract to the NVEOL as interpreted and extended by ASL for use in the Electro-Optical Systems Atmospheric Effects Library 80 (EOSAEL 80). The model is unique in its approach to transport and diffusion in that it treats the cloud as either a homogeneous ellipsoid (instantaneous source) or cone (semicontinuous sources) with major axes which increase linearly with time according to empirically derived diffusion parameters. The model uses the Briggs[11] formulation for buoyancy effects. Optical calculations include only effects due to extinction of electromagnetic radiation by smoke. The model incorporates variable burn rates and corresponding variable buoyancy rates.

The GRNADE Model[12] was developed by the Lockheed Missile and Space Company, under contract to the US Army Missile Research and Development Command (MIRADCOM) as part of a larger effort known as the Battlefield Environment Laser Designator Weapons System Simulation (BELDWSS). The model is specifically designed to calculate transmission through smoke produced by the self-screening L8A1 grenade normally launched from a battle tank. A

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[7]J. E. Selby et al, 1978, "Atmospheric Transmittance/Radiance: Computer Code LOWTRAN 4," Environmental Research Papers, No. 626, AFGL-TR-78-0053, Air Force Geophysics Laboratory, Hanscom Air Force Base, MA

[8]L. D. Duncan, editor, 1981, EOSAEL 80, Volume I, Technical Documentation, ASL-TR-0072, US Army Atmospheric Sciences Laboratory, White Sands Missile Range, NM

[9]R. C. Shirkey and S. G. O'Brien, editors, 1981, EOSAEL 80, Volume II, Users Manual, ASL-TR-0073, US Army Atmospheric Sciences Laboratory, White Sands Missile Range, NM

[10]R. Zirkind, 1978, An Obscuring Aerosol Dispersion Model, General Research Corporation Report CR-23V, Volumes 1 and 2, McClean, VA

[11]G. A. Briggs, 1969, "Plume Rise," US Atomic Energy Commission Critical Review Series," TID-25075

[12]C. H. Hayes, 1978, Self Screening Grenade Smoke Model for Battlefield Environment Laser Designator Weapon System Simulation (BELDWSS), Contract Report under Contract DAAK40-77-A-0010 for US Army Missile Research and Development Command, Redstone Arsenal, AL

geometrical line source formulation, vertical Gaussian diffusion, and Beer's law extinction are assumed throughout. A slightly modified version of GRNADE was adapted as a submodule in EOSAEL.

The BURN Model[13] was also developed under the BELDWSS program and is specifically designed to calculate transmission through smoke produced by a burning battle tank. This model is one of the few models found to date which treat fire smoke directly.

The FIRE Model[14] was recently developed by the General Electric - TEMPO Company under contract to the ASL. The specific purpose of the model is to serve as a heat source submodel for an optical turbulence model presently in the research phase at ASL. The model is somewhat deficient for immediate purposes of obscuration modeling, but it was chosen for the study because of its unique outputs--cloud temperature and particle flux density--both important for full extension of present models to infrared and millimeter systems.

The STILES Model[15] was developed by G. J. Stiles of the US Army Materiel Systems Analysis Activity (AMSAA). The purpose of the model is to give a quick estimate of munition expenditures for continuous smoke sources for a required screen height and length. The model treats only transmission and is intended for use with a small hand-held programmable calculator.

The SEMM Model[16] was developed by AMSAA for the JTCG/ME and is designed to calculate an expected smoke screen length and duration for a given deployment of munitions. The model performs this calculation by first deploying the transport and diffusion portion of the previously mentioned model SOM I and then sampling the resultant screen through various lines of sight. Screen edges are then defined by comparison of transmission through the screen with sensor threshold.

The model treats munition placement errors by repeating many scenarios with randomly selected burst points characteristic of the delivery system and

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[13]C. H. Hayes, 1979, Burning Vehicle Cloud Model for Battlefield Environment Simulations, Contract Report under Contract DAAK40-77-A-0010 for US Army Missile Research and Development Command, Redstone Arsenal, AL

[14]J. H. Thompson, 1980, Fire Plumes Modeling Progress Report, Contractor Report under Contract DAAD07-80-C-0072, US Army Atmospheric Sciences Laboratory, White Sands Missile Range, NM

[15]G. J. Stiles, 1978, "A Simple Model for Calculating Smoke Munition Requirements," US Army Materiel Systems Analysis Activity Interim Note No. G-47, Aberdeen Proving Ground, MD

[16]Smoke Effectiveness Manual, 1979, JTCG/ME Smoke and Aerosol Working Group Document Number FM 101-61-8

consequently requires a large amount of computer time. Two versions of the model are: one for instantaneous sources (white phosphorous [WP]) and the other for semicontinuous sources hexachloroethane [HC]). The model addresses transmission through smoke only and ignores ambient atmospheric transmission and contrast.

The KWIK Model[17] was developed by Umstead, Hansen, and Pena of ASL and is designed to give quick estimates of smoke munition delivery rates and spacings necessary to establish and maintain a smoke screen of given length and duration. The model specifically addresses 105-mm and 155-mm artillery for either HC or WP smoke munitions. Transmissions through both smoke and ambient atmospheres are treated by empirical means. There is an underlying assumption of Gaussian diffusion in the derivation of the equations of the model, but formulation of the diffusion parameters are unique and empirical. Screen effectiveness is based upon transmission and sensor threshold.

The MUNXP Model[18] was developed by R. O. Pennsyle of CSL. The model is designed to estimate munition placements and firing rates for the most efficient smoke screening for given munition type and number. The model is unique in that it assumes no particular diffusion or optical model but instead employs the ACT I model to determine salient characteristics of a single cloud and then uses these data as input. Two versions of the model are available: one for instantaneous sources and the other for semicontinuous sources. The second version uses a Monte Carlo procedure for calculating the effects of munition placement errors for headwind-tailwind scenarios.

The DIRTRAN (EOSAEL) Model[19] was developed by the Aerodyne Corporation Inc. under contract with the ASL. The model is designed to calculate transmission through vehicular dust and dust and debris produced by HE explosives for desert and European soil. A version of the model is presently being used in EOSAEL 80. The model is unique in the basic treatment of transport and diffusion in that it uses a numercial approach to the solution of vertical diffusion rather than the more usual Gaussian-Briggs formulation. An average extinction coefficient is used for the cloud, based on empirical data from field tests.

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[17] R. K. Umstead, R. Pena, and P. V. Hansen, 1979, KWIK: An Algorithm for Calculating Munition Expenditures for Smoke Screening/Obscuration in Tactical Situations, ASL-TR-0030, US Army Atmospheric Sciences Laboratory, White Sands Missile Range, NM

[18] R. O. Pennsyle, 1979, Methodology for Estimating Smoke/Obscurant Munition Expenditure Requirements, ARCSL-TR-79022, Chemical Systems Laboratory, Aberdeen Proving Ground, MD

[19] D. Dvore, DIRTRAN-I Users Manual, 1978, ARI-RR-178, Aerodyne Research, Inc., Bedford, MA

The ASL-DUST Model[20] was developed by the General Electric - TEMPO Company under contract with the ASL. The purpose of this model is similar to that of the DIRTRAN model although the approach to diffusion is Gaussian with size fractionalization to account for gravitational settling of different size particles. Extinction is computed for each size group. Transmission, backscatter, and thermal emmission are predicted for input lines of sight. Development is toward characterization of general soils.

The HEDUST Model[21] is similar in principle to the GRNADE and BURN models and was developed under the same BELDWSS effort. The purpose of this model is similar to that of the ASL DUST and DIRTRAN models. The HEDUST model was developed before the dusty infrared tests, and the development lacked the source characteristics data vital to the development and evaluation of a dust model for obscuration due to different soil types, cratering and initial cloud formation. These are required of the user.

The ACT II Model[22] is an upgraded transport, diffusion, and single scattering (optical) routine superseding the ACT I model described earlier. The transport and diffusion methodology is similar to most other models in that the basic assumption is Gaussian diffusion. Major improvements, however, are the inclusion of cloud temperature computations and an approach to buoyant motion based upon first principles rather than the empirical methods.

Other major improvements are the method of using a solution to the radiative transfer equation which includes effects of infrared (thermal) emission as well as single scattering and extinction. This method essentially expands present modeling capabilities to include contrast effects from the visible

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[20] J. H. Thompson, 1980, ASL-DUST: A Tactical Battlefield Dust Cloud and Propagation Code, Volume 1 - Model Formulations, Volume 2 - Users Guide, Contractor Report under Contract DAAD07-79-C-0143, US Army Atmospheric Sciences Laboratory, White Sands Missile Range, NM

[21] C. H. Hayes, 1978, High Explosive Dust Model for Battlefield Environment Laser Designator Weapon System Simulation (BELDWSS), Contract Report DAAK40-77-A-0010, US Army Missile Command, Redstone Arsenal, AL

[22] R. A. Sutherland and D. W. Hoock, 1981, An Improved Smoke Obscuration Model ACT II, Part 1: Theory, Technical Report, US Army Atmospheric Sciences Laboratory, White Sands Missile Range, NM (in process)

through the far infrared wavelengths. The ACT II model has produced favorable comparisons of modeled path luminance with field measurements from the Smoke Week data base.[23] [24]

The model is generally intended for inventory smoke munitions; however, many of the conclusions concerning battlefield significance drawn from applications studies with the model[25] also apply to other obscurants such as dust.

2.2 Data Sets

Eighteen Army field tests, thirteen primarily concerned with smoke and five primarily concerned with dust dating from 1975 to the present, were chosen for the study. The study consists of field tests only and does not include laboratory tests determining particle size and optical characteristics, most of which have been performed at CSL and ASL.

This report only includes those field tests that are major in scope and provide data required to develop, refine, or validate the variety of obscurant models. Tests performed to investigate only a narrow range of parameters specific to particular models have been excluded. Thus, the tests included here generally provide sufficient description of: obscurant source, location, and dissemination history; timing and spatial records of cloud formation, transport, and expansion; meteorological measurements to characterize the cloud environment; fundamental measurements of attenuation, brightness, extinction coefficient, size distribution, and/or concentration to characterize resultant obscuration by the cloud. (How well each test covers these topics is discussed in the cross-references of later sections.) Additionally, the many yearly tests of prototype or developing electro-optical systems in which obscurants were an incidental part have not been included. Similarly, the report excludes sensor data from major field tests, when such data have been taken by contractors for the purpose of system development and have not been made widely available to the obscurant modeling community.

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[23]R. A. Sutherland, 1981, "Comparisons Between the Upgraded Model ACT II and Recent Smoke Week Tests," Proceedings of Smoke Symposium V, Harry Diamond Laboratories, Adelphi, MD

[24]R. A. Sutherland, 1981, "Analysis of Current Electro-Optical Modeling and Field Testing in the Smoked Environment," Proceedings of the 25th Technical Symposium of the Society of Photometric Instrumentation Engineers (SPIE), San Diego, CA

[25]D. W. Hoock and R. A. Sutherland, 1981, "Computed Path to Background Luminance Ratios for Obscuring Smoke Clouds," Proceedings of Smoke Symposium V, Harry Diamond Laboratories, Adelphi, MD

The following paragraphs give a brief description of each of the tests. Further information can be found in the cited references and in the recently published Summary of Smoke Obscuration Test Data, Joint Munitions Effectiveness Manual of the JTCG/ME Smoke and Aerosol Working Group.[26]

Basic Smoke Characterization Test[27] (Dugway, 1978) - 19 December 1977 to 25 January 1978, Dugway Proving Ground, Utah. The purpose of these 18 laboratory (wind tunnel) and 18 field trails was to provide source characteristics of 9 inventory smoke submunition types. Analysis also led to burn rate profiles, estimates of burn duration, and initial source sigmas. Such measurements are very valuable in smoke modeling. However, little testing of this type has been done on newer munitions.

Jefferson Proving Ground Smoke Test[28] (AMSAA, 1977) - 19 to 21 August 1975, Jefferson Proving Ground, Indiana. Forty-one trials involving seven inventory smoke munitions and submunitions were performed to estimate smoke cloud dimensions as a function of time. Munitions were detonated both statically and dynamically. Film provided cloud height, width, and centroid position as a function of time as well as source sigmas. Optical properties of smoke were not measured. Data from this test provided the basis for development or validation of cloud rise and expansion for several models.

Fort Sill Smoke Test[29] - 8 to 16 December 1975, Fort Sill, Oklahoma. At least fourteen trials using six inventory smoke munition types were performed through dynamic firing. Optical attenuation and contrast were determined in the visible. Attenuations in the near infrared, mid infrared, and far infrared were also measured. No formal test report is available. Data from other trials were not fully reduced.

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[26] Summary of Smoke Obscuration Test Data, Joint Munitions Effectiveness Manual, 1979, Smoke and Aerosol Working Group, 61 JTCG/ME-79-2, Aberdeen Proving Ground, MD

[27] Basic Smoke Characterization - Phase I, Final Test Report, 1978, DPG Document DPG-TP-77-311 (DDC ADB03110L), Dugway Proving Ground, UT

[28] Analysis of the Smoke Cloud Data from the August 1975 Jefferson Proving Ground Smoke Test, 1977, AMSAA Technical Report TR-201 (AD A045874), Aberdeen Proving Ground, MD

[29] W. T. Hirnyck, 1975, Fort Sill Smoke Test Information: Test Data for Fort Sill Smoke Tests, US Army Materiel Systems Analysis Activity, Aberdeen Proving Ground, MD

White Sands Missile Range Smoke Test[30] (PM Smoke, 1978) - 12 to 21 July 1977, White Sands Missile Range, New Mexico. Ten trials using four smoke munition types, statically detonated, were used to evaluate performance of various thermal night sights, day sights, EO tracking links, and beam rider guidance systems. Smoke was fully characterized by aerosol photometers, chemical impingers, and particle size analyzers. Transmission and lidar instrumentation were also used. Smoke concentration path lengths were time correlated with equipment performance data. Usefulness to obscurant models is limited, however, because the precise positioning of targets and detectors and the actual numbers and positions of malfunctioning munitions are unknown.

Inventory Smoke Munitions Test - Phase IIa[31] (Dugway, 1978) - 23 September to 2 November 1977, Dugway Proving Ground, Utah. Twenty-two trials involving eight smoke munition and submunition types, statically detonated, were performed in this preliminary series preceding Smoke Week I. Comprehensive measurements were made of smoke cloud dimensions and of optical properties (through transmissometer measurement along three lines of sight in the visible, near infrared, mid infrared, and far infrared, aerosol photometer and chemical impinger measurements along the center line of sight, and particle size analyzer data). The test report does not precisely define the separation of munitions about the reported central position. Meteorological conditions were fully reported. Users of trials for which munition placement is reported as 30 m from the central line should be cautioned that these locations are apparently in error since data shows smoke passed through the upwind line of sight 60 m from the central line. This data set comprises the earliest attempt to fully characterize obscurant clouds and optical effects and is one of the most useful to modelers.

Smoke Grenade, RP, L8A1 Test - Phase IIb[32] (Dugway, 1978) - 31 October to 2 November 1977, Dugway Proving Ground, Utah. Eight trails of the L8A1 grenade, fired dynamically from tube launchers, were performed by using the measurement procedures of the inventory smoke munitions test. Launch points and directions are reported; however, impact points are not provided. Data from this test permitted the development and validation of smoke grenade models.

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[30] Manportable Common Thermal Night Sight Smoke Test at White Sands Missile Range - July 1977 (U), CONFIDENTIAL, 1978, PM-SMK-T-001-78 (AD C015243) Project Manager Smoke/Obscurants, Aberdeen Proving Ground, MD

[31] Inventory Smoke Munitions Test - Phase IIa, Final Test Report, 1978, Volumes I and II, DPG-FR-77-311 (AD B031191L), Dugway Proving Ground, UT

[32] Smoke Test of the Grenade, RP L8A1 - Phase IIb, Final Test Report, 1978, Volumes I and II, DPG-FR-315 (AD B031193L, AD B031194L), Dugway Proving Ground, UT

Smoke Week I Test[33] (PM Smoke, 1978) - 15 to 19 November 1977, Dugway Proving Ground, Utah. Twelve trials were performed with three types of statically detonated inventory smoke munitions, dynamically fired L8A1 grenades, and four foreign smoke munitions. This test allowed evaluation of performance of several EO systems in the smoke environment as measured alongside the Dugway instrumentation used in the inventory and grenade smoke munition tests. Three trials took place at night.

Foreign Smoke Munitions Test - Phase III[34] (Dugway, 1978) - 20 to 28 November 1977, Dugway Proving Ground, Utah. Twelve trials of four types of foreign smoke munitions were made with the Dugway instrumentation and EO sensors. The number of munitions of each type was increased for each of three trials, with each group of trials performed generally within a 90-min period, thus permitting scaling checks of smoke model predictions.

Smoke Week II Test[35] [36] (Dugway, 1978, PM Smoke, 1979) - 6 to 16 November 1978, Eglin Air Force Base, Florida. Thirty-one trials were performed involving nine inventory and foreign smoke munitions, experimental smoke munitions, burning hulks, C4 produced dust, and vehicular dust. Performance of EO systems was evaluated and obscurant measurements were provided by Dugway instrumentation and photographs by Armament Development and Test Center, Eglin Air Force Base. Lines of sight included horizontal, vertical, and slant path measurements. Slant path data aid in modeling obscuration and cloud buoyancy above the first few meters.

High Humidity Hygroscopic Smoke Test - H^3S[37] (Dugway, 1980) - 19 to 22 July 1979, Aberdeen Proving Ground, Maryland. Twenty-seven trials using four types of smoke munitions were made under conditions of high relative humidity. Extensive measurements comparable to Smoke Week II and the inventory

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[33] Smoke Week I, Electro-Optical (EO) Systems Performance in Characterized Smoke Environment at Dugway Proving Ground, UT - Nov 77 (U), CONFIDENTIAL, 1978, DRPCM-SMK-T-002-78, (AD C015328), Project Manager, Smoke/Obscurants, Aberdeen Proving Ground, MD

[34] Foreign Smoke Munitions Test - Phase III, Final Test Report, 1978, Volumes I and II, DPG-FR-77-316 (AD B031195L, AD B031196L), Dugway Proving Ground, UT

[35] Smoke Week II Electro-Optical (EO) Systems in Characterized Obscured Environment at Eglin AFB, FL, Nov 78 (U), CONFIDENTIAL, 1979, DRCPM-SMK-T-001-79, Project Manager, Smoke/Obscurants, Aberdeen Proving Ground, MD

[36] DPG Final Test Report on Smoke Week II at Eglin AFB, FL, (U), CONFIDENTIAL, 1978, Volumes I and II, DPG-FR-78-317, Dugway Proving Ground, UT

[37] High Humidity Hygroscopic Smoke Test, Final Test Report, 1980, Volumes I and II, DPG-FR-79-310, Dugway Proving Ground, UT

smoke munitions test were made. The clouds passed beyond the end of the chemical impinger line in several trials, thus reducing some of the usefulness to cloud development modeling. However, valuable data were obtained to test yield factor dependence on relative humidity, and extinction coefficient dependence on relative humidity and time. Current models assume only wavelength dependence for extinction.

Dust Trial Phase of Inventory Smoke Munition Test - Phase IIa[38] (Dugway, 1978) - 19 November to 1 December 1977, Dugway Proving Ground, Utah. Six trials using statically detonated TNT charges were performed to simulate six types of HE munitions. The Dugway instrumentation of the inventory smoke munitions test was used. These data provided information for initial development of dust models, although crater dimensions were not measured.

Dust/Debris Test[39 40] (Dugway, 1978, 1979) - 14 to 17 May 1978, Fort Sill, Oklahoma. Twenty-four trials of obscuration by dust were performed using two types of dynamically fired HE projectiles and moving vehicles. Dugway instrumentation measured transmission along three lines of sight in the visible, near infrared, mid infrared, and far infrared. Particle size analyses and films were also produced. Reported impact points for multiple firings represent the center of impact. Cloud rise and expansion data were useful in dust model refinement.

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[38] Dust Trial Phase of Inventory Smoke Munition Test - Phase IIa, Final Test Report, 1978, DPG-FR-77-314 (AD B031197L), Dugway Proving Ground, UT

[39] Dust/Debris Test Conducted at Fort Sill, OK, by DPG, Final Test Report, 1978, Volumes I and II, DPG-FR-78-313, (AD A066377, AD A06339110), Dugway Proving Ground, UT

[40] Dust/Debris Field Test Add-on, 1979, DPG-FR-78-313 Add-on, Dugway Proving Ground, UT

Dusty Infrared Test I[41-44] (DIRT-I, 1979) - 2 to 14 October 1978, White Sands Missile Range, New Mexico. Eighteen trials of static TNT charges at measured depths and 18 trials of both static and live fire 155-mm HE projectiles were used to characterize transmission through explosive produced dust. Visible, infrared, and 94 GHz transmission were measured. The soil was analyzed as sandy in texture. Crater volumes and positions were measured. One trial of burning diesel fuel, motor oil, and rubber was performed. Comparison between TNT and 155-mm-produced craters provided charge equivalency. Airborne instrumentation was used for cloud sampling. Explosions were on or very near the line of sight.

Dusty Infrared Test II[45] (DIRT-II, 1980) - 18 to 28 July 1979, White Sands Missile Range, New Mexico. Transmission through HE generated dust in a silty-clay soil texture was measured for 30 events which involved static and live fire of 105-mm, 155-mm, and 4.2-inch HE projectiles as well as scaled C4 explosions. Soil properties were analyzed and crater dimensions were measured as well as cloud dimensions and transmission at various wavelengths through the cloud, including 94 GHz. Explosions of single munitions upwind of the line of sight aided in development of dust cloud transport and buoyant fireball modeling.

Dusty Infrared Test III[46] (DIRT-III, 1981) - 14 April to 1 May 1980, Fort Polk, Louisiana. Unlike the earlier DIRT series which were conducted in a desert environment, DIRT-III explosions took place in a forest clearing in predominantly moist soil. Forty-four trials were performed using statically detonated United States and foreign munitions and C4 explosives in the natural

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[41] J. E. Van der Laan, 1979, Lidar Observations at 0.7km and 10.6μm Wavelengths During Dusty Infrared Test I (DIRT I), 1979, ASL-CR-79-0001-2, US Army Atmospheric Sciences Laboratory, White Sands Missile Range, NM

[42] J. D. Lindberg, editor, 1979, Measured Effects on Battlefield Dust and Smoke on Visible, Infrared and Millimeter Wavelength Propagation: A Preliminary Report on the Dust Infrared Test I (DIRT I), ASL-TR-0021, US Army Atmospheric Sciences Laboratory, White Sands Missile Range, NM

[43] Chavez, 1979, Fixed Camera Data, Infrared Test I, 2-14 October 1978, Final Report 37179, Physical Science Laboratory, New Mexico State University, Las Cruces, NM

[44] C. A. Miller and B. W. Kennedy, 1979, Terrain Characteristics at DIRT I Test Site, White Sands Missile Range, NM, ASL-IAO-79-8146-1, US Army Atmospheric Sciences Laboratory, White Sands Missile Range, NM

[45] B. W. Kennedy, 1980, Dusty Infrared Test II (DIRT-II) Program, ASL-TR-0058, US Army Atmospheric Sciences Laboratory, White Sands Missile Range, NM

[46] B. W. Kennedy, 1981, Dusty Infrared Test III (DIRT-III) Project Summary, Internal Report, US Army Atmospheric Sciences Laboratory, White Sands Missile Range, NM (final test report in progress)

soil both on and off the optical axis. Forty-four trials were then performed in soils specifically tailored in texture, composition, and moisture content. Transmission at visible, near infrared, mid infrared, far infrared, and near millimeter wavelengths were measured. Cloud dimensions were derived from digital imagery. Extensive meteorological measurements of the forested test area were also taken.

Smoke Week III Test[47] (Dugway, 1980) - 11 to 20 August 1980, Eglin Air Force Base, Florida. Forty-two trials were conducted, of which only one (trial 13) was unsuccessful. Obscurants included WP, RP, PWP, HC, Fog Oil, Diesel Oil, Polyethyleneglycol (PEG 200), alkali chloride, experimental smokes (IR1, IR2, IR3) and dust.

Smoke Week III contained perhaps the most comprehensive and coordinated data found to date. Transmission measurements were made along four lines of sight, including one along the vertical, all at wavelengths from the visible through the infrared. Both path luminance and path radiance (far infrared) were measured. Environmental characterization included sun and sky radiation measurements and extensive micrometeorological measurements. Path integrated concentration (CL) was also measured at varied points along two lines of sight.

Documentation for the test was concise and nearly complete, including coordinates for all sensors, instrumental spectral bandpasses and estimated instrumental error limits. Unfortunately, the test report does not include the extremely important source locations, although this information was recorded and is available from the OPM Smoke/Obscurants. An error misplaces the x axis heading in the test configuration[47] and should be changed to give an x axis heading of 105°57'14" from north.

Battlefield Environment Laser Designator Weapon System Simulation Phase III (BELDWSS)[48 49] - September 1979 to June 1980, Redstone Arsenal, Alabama. This extended period of tests of laser designator and electro-optical sensors included smoke (HC and L8A1 grenade), HE dust (C4 equivalent), vehicular dust

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[47]H. M. Smalley, 1981, Final Report, Smoke Week III (SW III), DPG-FR-80-305, Dugway Proving Ground, UT

[48]M. Maddix et al, 1981, BELDWSS Phase III Field Test Data, TADS Tracking Performance in Battlefield Environments (U), CONFIDENTIAL, SR-RG-81-3 to 9, US Army Missile Command, Redstone Arsenal, AL

[49]E. H. Talley, 1981, Final Report, Phase III, AAH/Hellfire Battlefield Obscuration Program, Teledyne Brown Engineering, SD81-MICOM-2534, for US Army Missile Command, Huntsville, AL

and fire products. In more than two hundred trials the obscurant cloud properties were measured directly by transmissometer (visible, near infrared, mid infrared, and far infrared), radiometers, particle size analysers, and the EO sensors. Average meteorological conditions were recorded for each trial. Unfortunately, the locations of the munition sources with reference to the test grid were not always clearly indicated. A follow-on series (Phase IV) provides further data of a similar type.

Grafenwöehr II (GRAF II)[50] - 8 to 26 November 1978 and 18 to 30 June 1979, Grafenwöehr, Germany. This test of the effect of single and barrage HE explosions and inventory smoke munitions was carried out in two phases, the GRAF II Winter and GRAF II Summer tests. Fourteen HE barrages were included in the winter trials. During the summer test eight trials of HE barrages, eleven single static HE explosions, and seven inventory smoke trials were performed. Clouds were characterized by transmission (visible, near infrared, mid infrared, far infrared, and millimeter wavelengths), particle size analysis, and output from the various sensors. Soil conditions were analyzed as a silty loam, wet in the winter and dry to moist in the summer.

2.3 Summary

Almost all the models and data sets in some way treat transmission effects of inventory smokes in visible scenarios, and some treat path luminance and contrast. In addition, most of the models do or could treat infrared transmission effects, and one treats infrared path radiance. None of the models surveyed account for the stochastic nature of obscurant transport and diffusion required to include clutter effects nor do any models treat the special optical problems encountered in the millimeter spectral region.

In other areas model improvement, validation, and extension have been continuing. The additions to the SEMM model which improve validation have not been included.[51] Also the KWIK model has been upgraded to better treat atmospheric transmission and to extend the concept of screening to include system contrast sensitivity for use in EOSAEL. Also in the interim period since the initiation of the study, new methods have been reported for the problem of

[50]J. Moulton et al, 1980, Grafenwöehr II, Realistic Battlefield Trials (U), CONFIDENTIAL, DELNV-TR-0013, Night Vision and Electro-Optics Laboratory, Fort Belvoir, VA

[51]"Revision to the Smoke Effectiveness Manual Model (SEMM)," 1980, Interim Note F-18, Field Equipment and Technology Division, US Army Materiel Systems Analyses Activity, Aberdeen Proving Ground, MD

windborne natural dust* and for new munitions which require methods for treating extended area sources.[52] A specialized test to check munition expenditures models has been planned and partially executed (KWIK tests).[53] In another respect, this study does not include independent measurements sponsored by individual laboratories which are supplemental add-ons but not part of the overall test plan and not published in the official test reports.

3. THE TABLES AND DEFINITIONS

The model input requirements, output results, and data base measurements were separated into the following seven major categories:

Meteorological	Table 1
Source characteristics	Table 2
Atmosphere/soil/terrain	Table 3
Sensor/target/background	Table 4
Miscellaneous	Table 5
Computational/control	Table 6
Outputs	Table 7

All tables are in two parts: one for the models and one for the data bases.

In most cases, the choice of category for various inputs and outputs was straightforward. In other cases, the decision was more difficult, especially where a particular input could be classified in any one of many categories as, for example, in the case of parameters such as cloud entrainment coefficient. In these cases, the particular input was assigned to a single category rather than cross-referenced in multiple categories. Also, in actual usage some requirements, although referenced differently in different models, are not independent; for example, the wind direction is variously referred to as wind direction, wind vector, or wind vector direction cosines. Such inputs are classified under a single category so that the list will approximate an independent set of requirements. In cases where there might be ambiguity, the

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*"Air Pollution from Blowing Dust," unpublished US Army Atmospheric Sciences Laboratory communication

[52]S. L. Cohn, 1980, "Transport and Diffusion Solutions for Obscuration Using the XM-825 Smoke Munition," Proceedings of the Smoke/Obscurant Symposium IV, Adelphi, MD

[53]Battlefield Environments Division, 1979, "KWIK Smoke Munitions Expenditure Algorithm, Test Plan for Preliminary Evaluation," Draft Report, US Army Atmospheric Sciences Laboratory, White Sands Missile Range, NM

requirements were classified as though independent. The results of this study emphasize the desirability of standardizing inputs so that these complicating aspects can be removed in future studies.

In the tables, those data items generally required to exercise a particular model at its full capability (including all options) are designated with either an (R) or an (O) in the column under the indicated model. Those data labeled (O) are optional wherein the indicated model either provides a "default" value or offers an alternate methodology requiring (perhaps) some other optional data. For field test data, those items provided in the test reports are designated (D) and otherwise left blank. For table 7a (model outputs), those items output by the indicated model are designated (X) and otherwise left blank.

Definitions contained in the appendix clarify cases in which category and designation decisions were not straightforward. The definitions cover each numbered data item in the tables and often include explanations of how the particular data are generally used in the models. Many of the data items are common entities found in standard texts and in the contemporary literature. For specialized data, of concern only to the obscuration modeling community and sometimes only vaguely defined even in the model descriptions, multiple definitions for a single table entry are given and some input requirements are listed under the "best" classification. These latter cases are usually cited in the accompanying footnotes.

Additionally, table 8 identifies by type the various smoke, fire, or dust sources used in the test and gives the total number of trials for each.

4. DISCUSSION

The tables compiled in the previous section have several uses. One important use is as a guide for future tests and for further model validation studies. The study can also give users with specialized needs a quick method for comparing input requirements and outputs of models.

Probably the most urgent use for the study is to help pinpoint areas of deficiency in present modeling and testing. (This study does not address research level efforts to solve specialized modeling problems.) For example, one technical aspect which can be readily perceived simply by studying the tables is the relative dearth of capability in modeling contrast (table 7a), especially in the infrared. As might be expected, this neglect is reflected in the tests (table 7b), which to date have been slanted toward transmission determination. (The closely related measurements of path radiance in the later tests notwithstanding.)

Also missing in the modeling effort are some of the advanced concepts of obscuration, such as: optical turbulence, which has a marked effect on beam wander; and pulsed information degradation (that is, pulse stretching), which can be important in laser systems. (At the research level this lack is being addressed presently for the very important effects produced by battlefield fires.) The perhaps subtler effects of polarization are likewise ignored.

Also, except for the trivial case of transmission through the nearly transparent inventory smokes, modeling capabilities in the near millimeter spectral region are totally lacking. Again, except for the DIRT series, this lack is reflected in the test data.

In the area of transport and diffusion, except for the (albeit important) details, most of the models are alike, usually assuming mean wind transport and Gaussian diffusion. These assumptions point out a neglect in modeling the stochastic or statistical nature of smoke clouds, a neglect which is evidenced by the meandering and clustering of real world plumes.[54] (This problem is being addressed at the research level.)[55]

A positive factor is that the modeling and measurement efforts thus far have lead to a better evaluation of inventory munition effectiveness and to some insight as to the characteristics which may improve screening effectiveness. Also, the preliminary analysis of the DIRT (including DIRT-III) tests has uncovered important multispectral effects which probably could not have been anticipated without these observations.

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[54] R. A. Sutherland, 1980, "Electro-Optical Obscuration due to Inadvertent Battlefield Fire Smokes," Proceedings of the Smoke/Obscurants Symposium IV, Adelphi, MD

[55] W. D. Ohmstede and E. B. Stenmark, 1980, "A Model for Characterizing Transport and Diffusion of Air Pollution in the Battlefield Environment," Second Joint Conference on Applications of Air Pollution Meteorology and Second Conference on Industrial Meteorology, American Meteorological Society

TABLE 1a. METEOROLOGICAL

MODEL NAME

	ACT I	HECSOM	SOM II	SMOKE	GRNADE	BURN	FIRE	STILES	SEMM	KWIK	MUNXP	ASL DUST	DIRTRAN	HEDUST	ACT II
1. Windspeed	R	R	R	R	R	R		R	R	R	R	R	R	R	R
2. Wind direction	R	R	R	R	R	R		R	R	R	R	R	R	R	R
3. Standard deviations	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
a. Windspeed															
b. Wind azimuth		R	0												
c. Wind elevation		R	0												
d. Other															
4. Power law exponent (wind)		R	R		R	R						R		R	R
5. Gradient (wind azimuth)		R													
6. Temperature (ambient)		0		R			R			R		R	R		R
7. Gradient (temperature)		0	R	R			R					R			R
8. Reference heights	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
a. Wind		R	R									R	R		R
b. Temperature		R											R		R
c. Other															
9. Sampling rate/time		0	0												
10. Air density		0										0			
11. Air pressure							R								
12. Relative humidity				R											0
13. Dew point temperature										R					0
14. Mixing height		R	R												0
15. Inversion height					R	R									0
16. Ceiling										R					
17. Cloud cover										R					
18. Net radiation															0
19. Visibility			0							R					
20. Stability category			0	R	R							0	0		R
21. Adverse weather	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
a. Type			R												
b. Height	R	R													
c. Extinction coefficient	R	R													R
d. Haze level			0												
e. Other															
22. Precipitation	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
a. Yes/no										R					
b. Type															
c. Rate (light, heavy, etc.)		0													
d. Rate (mm/hr)															
23. Radiosonde data			0												
24. Coordinates															
25. Time series data															

TABLE 1b. METEOROLOGICAL

FIELD TEST NAME

	BSC SMOKE	JPG SMOKE	FT SILL SMOKE	WSMR SMOKE	PH IIA SMOKE	PH IIB SMOKE	SMOKE WK I	FOR SMOKE III	SMOKE WK II	H3S SMOKE	PH IIA DUST	DUST/DEBRIS	DIRT I	DIRT II	DIRT III	SMOKE WK III	GRAF II	BELDWSS III
1. Windspeed	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D
2. Wind direction		D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D
3. Standard deviations	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
a. Windspeed														D	D			
b. Wind azimuth				D	D	D	D	D	D		D			D	D	D		
c. Wind elevation				D	D	D	D	D	D		D			D	D	D		
d. Other																		
4. Power law exponent (wind)				D	D	D	D	D	D		D				D	D		
5. Gradient (wind azimuth)															D	D		D
6. Temperature (ambient)	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D
7. Gradient (temperature)			D	D	D	D	D	D	D		D		D	D	D	D	D	D
8. Reference heights	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
a. Wind	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D
b. Temperature	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D
c. Other																D		
9. Sampling rate/time															D	D		
10. Air density																D		
11. Air pressure					D	D	D	D	D		D			D	D	D		D
12. Relative humidity	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D
13. Dew point temperature															D	D		D
14. Mixing height																		
15. Inversion height													D	D	D			
16. Ceiling															D			D
17. Cloud cover		D	D		D	D		D	D	D	D	D	D	D	D	D		D
18. Net radiation					D	D	D	D	D	D	D			D	D	D		D
19. Visibility		D			D	D	D	D	D	D			D	D	D	D	D	D
20. Stability category			D	D	D	D	D	D	D	D	D				D	D	D	D
21. Adverse weather	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
a. Type															D	D		
b. Height																		
c. Extinction coefficient																		
d. Haze level											D					D		
e. Other																		
22. Precipitation	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
a. Yes/no	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D
b. Type																		
c. Rate (light, heavy, etc.)																D		
d. Rate (mm/hr)																		
23. Radiosonde data														D	D			
24. Coordinates (x, y)			D		D	D	D	D	D	D	D	D	D	D	D	D		D
25. Time series data															D			

TABLE 2a. SOURCE CHARACTERISTICS

MODEL NAME

	ACT I	HECSOM	SOM II	SMOKE	GRNADE	BURN	FIRE	STILES	SEMM	KWIK	MUNXP	ASL DUST	DIRTRAN	HEDUST	ACT II
1. Coordinates (sources)	R	R	R	R	R	R						R	R	R	R
2. Event time	R	R	R	R											R
3. Munition type		R		R											
4. Fill mass	R	0	0	0				R	R						R
5. Efficiency	R	0	R	0	R	R		R							R
6. Yield factor	R	R	R	0	R	R		R	R						0
7. Emission rate/duration	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
a. Parameters		0		0	0										R
b. Constant						R									
c. Point data															
d. Burn time		0	R	0					R						R
e. Other															
8. Cloud build-up time										R					
9. Source sigmas	R	0	R						R					R	
10. Equivalent TNT yield												R	R	R	
11. Hydro-yield												R			
12. Charge orientation													R		
13. Depth of charge													R		
14. Apparent crater volume												0			
15. Crater scaling factor												0			
16. Buoyant/nonbuoyant mass ratio												0			
17. Carbon emission factor												0			
18. Shape factors												0			
19. Heat yield		0	R									0	0		R
20. Initial cloud temperature							R								
21. Initial emission velocity							R								
22. Particulate bulk density			R												
23. Indices of refraction			R												
24. Mass extinction coefficient	R	R		0				R	R					R	R
25. Single scattering albedo															R
26. Mie scattering function	R	0													R
27. Particle size spectrum	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
a. Parameters			0												
b. Point data			0												
28. Size fractions												0			

TABLE 2b. SOURCE CHARACTERISTICS

FIELD TEST NAME

	BSC SMOKE	JPG SMOKE	FT SILL SMOKE	WSMR SMOKE	PH IIA SMOKE	PH IIB SMOKE	SMOKE WK I	FOR SMOKE III	SMOKE WK II	H3S SMOKE	PH IIA DUST	DUST/DEBRIS	DIRT I	DIRT II	DIRT III	SMOKE WK III	GRAF II	BELDWSS III
1. Coordinates (sources)	D		D	D	D	D	D	D	D	D	D	D	D	D	D	D		D
2. Event time	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D		D
3. Munition type	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D		D
4. Fill mass	D	D	D	D	D	D	D	D	D	D								
5. Efficiency	D																	
6. Yield factor	D	D			D	D	D	D	D	D						D		
7. Emission rate/duration	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
a. Parameters	D																	
b. Constant	D																	
c. Point data	D																	
d. Burn time	D																	
e. Other																		
8. Cloud buildup build-up time																		
9. Source sigmas	D	D											D	D	D			
10. Equivalent TNT yield									D		D	D	D	D	D	D		
11. Hydro-yield																		
12. Charge orientation									D		D	D	D	D	D			
13. Depth of charge									D		D		D	D	D			
14. Apparent crater volume													D	D	D			
15. Crater scaling factor														D	D			
16. Buoyant/nonbuoyant mass ratio																		
17. Carbon emission factor																		
18. Shape factors																		
19. Heat yield																		
20. Initial cloud temperature																		
21. Initial emission velocity																		
22. Particulate bulk density													D	D	D			
23. Indices of refraction														D	D			
24. Mass extinction coefficient					D	D	D	D	D	D	D	D				D		
25. Single scattering albedo																		
26. Mie scattering function																		
27. Particle size spectrum	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
a. Parameters	D			D	D	D	D	D	D	D	D	D	D	D	D	D		D
b. Point data	D			D	D	D	D	D	D	D	D	D	D	D	D	D	D	D
28. Size fractions																		

TABLE 3a. ATMOSPHERE/SOIL/TERRAIN

MODEL NAME

	ACT I	HECSOM	SOM II	SMOKE	GRNADE	BURN	FIRE	STILES	SEMM	KWIK	MUNXP	ASL DUST	DIRTRAN	HEDUST	ACT II
1. Ambient radiation	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
a. Solar irradiance	R	R	R												R
b. Global irradiance	R	R	R												R
c. Solar illuminance	R	R	R												0
d. Global illuminance	R	R	R												0
2. Sky radiation	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
a. Radiance	R	R	R												R
b. Luminance	R	R	R												0
3. Terrain radiation	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
a. Radiance	R	R	R												
b. Luminance	R	R	R												
4. Surface albedo	R	R													
5. Surface emissivity	R	R													
6. Soil characteristics	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
a. Type												0	0		
b. Bulk density												0			
c. Moisture content												0			
d. Depth of sod													0		
7. Terrain roughness			R							R					R
8. Ambient atmosphere	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
a. Standard atmospheres option			0												
b. Radiosonde data			0												
c. Transmittance data			0												
9. Reflection coefficient			R		0	R									R
10. Scavenging coefficient			R		R	R									
11. Entrainment coefficient		0	0									0			
12. Drag coefficient												0			
13. Settling velocity			R			R									
14. Diffusion function exponents	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
a. Alongwind			0												
b. Crosswind	R	0	0		0				R					R	
c. Vertical	R	0	0		0	R			R					R	
15. Diffusion reference lengths	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
a. Alongwind			0												
b. Crosswind		R	0			R									
c. Vertical		R	0			R									
16. Diffusion scaling lengths	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
a. Alongwind			0												
b. Crosswind		0	0	0											
c. Vertical		0	0		0	R									
17. Apparent rise angle								R							
18. Half width parameters											R				

TABLE 3b. ATMOSPHERE/SOIL/TERRAIN

FIELD TEST NAME

	BSC SMOKE	JPG SMOKE	FT SILL SMOKE	WSMR SMOKE	PH IIA SMOKE	PH IIB SMOKE	SMOKE WK I	FOR SMOKE III	SMOKE WK II	H3S SMOKE	PH IIA DUST	DUST/DEBRIS	DIRT I	DIRT II	DIRT III	SMOKE WK III	GRAF II	BELDWSS III
1. Ambient radiation	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
a. Solar irradiance					D	D	D	D	D	D	D			D	D	D		
b. Global irradiance					D	D	D		D	D						D		D
c. Solar illuminance																D		
d. Global illuminance																D		
2. Sky radiation	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
a. Radiance									D	D						D		
b. Luminance					D	D	D									D		
3. Terrain radiation	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
a. Radiance																		
b. Luminance																		
4. Surface albedo																		
5. Surface emissivity																		
6. Soil characteristics	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
a. Type											D		D	D	D	D		D
b. Bulk density													D	D	D	D		
c. Moisture content													D	D	D	D		
d. Depth of sod																D		
7. Terrain roughness																		
8. Ambient atmosphere	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
a. Standard atmospheres option																		
b. Radiosonde data													D	D	D			
c. Transmittance data																		
9. Reflection coefficient																		
10. Scavenging coefficient																		
11. Entrainment coefficient																		
12. Drag coefficient																		
13. Settling velocity																		
14. Diffusion function exponents	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
a. Alongwind																		
b. Crosswind																		
c. Vertical																		
15. Diffusion reference lengths	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
a. Alongwind																		
b. Crosswind																		
c. Vertical																		
16. Diffusion scaling lengths	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
a. Alongwind																		
b. Crosswind																		
c. Vertical																		
17. Apparent rise angle																		
18. Half width parameters		D			D	D	D	D	D		D	D	D	D	D	D		D

TABLE 4a. SENSOR/TARGET/BACKGROUND

MODEL NAME

		ACT I	HECSOM	SOM II	SMOKE	GRNADE	BURN	FIRE	STILES	SEMM	KWIK	MUNXP	ASL DUST	DIRTRAN	HEDUST	ACT II
1.	Coordinates (sensor)	R	R	R	R	R	R						O	R	R	R
2.	Type (sensor)			R												
3.	Wavelength (sensor)			R		R	R						O	R	R	R
4.	Bandpass			R												R
5.	Threshold (transmission)					R	R		R	R					R	
6.	Threshold (contrast)	R	R													
7.	Threshold (resolvable cycles)			R												
8.	Aperture			R												
9.	Field of view			R												
10.	Coordinates (target)	R		R	R	R									R	R
11.	Type (target)			R												
12.	Equivalent area (target)			R												
13.	Minimum dimension (target)			R												
14.	Reflectivity/emissivity (target)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	a. Visible/photopic	R	R	R												R
	b. Infrared	R	R	R												R
	c. Other															
15.	Temperature (target)			R												R
16.	Radiance/luminance (target)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	a. Visible/photopic	R	R	R												
	b. Infrared	R	R	R												
	c. Other															
17.	Coordinates (background)			O												
18.	Type (background)			R												
19.	Reflectivity/emissivity (background)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	a. Visible/photopic	R	R	R												R
	b. Infrared	R	R	R												R
	c. Other															
20.	Temperature (background)			R												R
21.	Radiance/luminance (background)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	a. Visible/photopic			R												
	b. Infrared			R												
	c. Other															
22.	Other	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	a. Sensor/target velocity			R												
	b. Target-background distance	R	R	O												R
	c. Target-background velocity			P												
	d. Sensor-cloud distance									R						
	e. Light level (at target)			R												
	f. Line-of-sight direction			O							R					
	g. Slant range			O							R	R				
	h. Target cover type			R												

TABLE 4b. SENSOR/TARGET/BACKGROUND

FIELD TEST NAME

	BSC SMOKE	JPG SMOKE	FT SILL SMOKE	WSMR SMOKE	PH IIA SMOKE	PH IIB SMOKE	SMOKE WK I	FOR SMOKE III	SMOKE WK II	H3S SMOKE	PH IIA DUST	DUST/DEBRIS	DIRT I	DIRT II	DIRT III	SMOKE WK III	GRAF II	BELDWSS III
1. Coordinates (sensor)	D		D		D	D	D	D	D	D	D	D	D	D	D	D		D
2. Type (sensor)	D		D		D	D	D	D	D	D	D	D	D	D	D	D	D	D
3. Wavelength (sensor)	D		D		D	D	D	D	D	D	D	D	D	D	D	D	D	D
4. Bandpass										D						D	D	
5. Threshold (transmission)																	D	
6. Threshold (contrast)																	D	
7. Threshold (resolvable cycles)																	D	
8. Aperture													D	D	D	D		
9. Field of view													D	D	D	D	D	
10. Coordinates (target)			D	D	D	D	D	D	D	D	D	D	D	D	D	D		D
11. Type (target)			D		D	D	D	D	D	D	D				D	D	D	D
12. Equivalent area (target)			D		D	D	D	D	D	D	D	·						D
13. Minimum dimension (target)																	D	D
14. Reflectivity/emissivity (target)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
a. Visible/photopic										D								D
b. Infrared																		D
c. Other																		
15. Temperature (target)																	D	D
16. Radiance/luminance (target)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
a. Visible/photopic										D						D		D
b. Infrared																D		D
c. Other																		
17. Coordinates (background)			D	D					D	D								D
18. Type (background)			D	D					D	D								D
19. Reflectivity/emissivity (background)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
a. Visible/photopic																		D
b. Infrared																		D
c. Other																		
20. Temperature (background)																		D
21. Radiance/luminance (background)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
a. Visible/photopic					D	D	D	D	D	D								D
b. Infrared																		D
c. Other																		
22. Other	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
a. Sensor/target velocity																	D	D
b. Target-background distance			D	D					D								D	D
c. Target-background velocity																		D
d. Sensor-cloud distance																		D
e. Light level (at target)																		
f. Line-of-sight direction			D		D	D	D	D	D	D	D	D	D	D	D	D		D
g. Slant range			D		D	D	D	D	D	D	D	D	D	D	D	D	D	D
h. Target cover type																		

TABLE 5a. MISCELLANEOUS

	MODEL NAME: ACT I	HECSOM	SOM II	SMOKE	GRNADE	BURN	FIRE	STILES	SEMM	KWIK	MUNXP	ASL DUST	DIRTRAN	HEDUST	ACT II
1. Coordinates (delivery system)			R		R				R		R				
2. Delivery system data	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
a. Type															
b. Maximum range									R		R				
c. Maximum rate/duration											R				
d. Precision error									R						
e. Aiming error			R						R						
f. Reliability (of round)									R						
3. Submunition data	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
a. Submunitions/round			R						R		R				
b. Fill mass	R	R	R	R					R						R
c. Burst height	R	R	R												R
4. Submunition impact pattern			R								R				
5. Volley data	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
a. Aim points			R						R						
b. Ideal impact points/spacings			O						R						
c. Number rounds per volley									R						
d. Number of volleys									R						
e. Volley rate									R						
6. Screening data (a priori)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
a. Height											R				
b. Length															
c. Width											R				
d. Duration											R				
e. Formation time											R				
f. Fractional coverage											R				
g. Available systems (number)											R				
h. Available rounds (number)															
7. Laser designator	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
a. Coordinates	R	R													
b. Intensity	R	R													
c. Wavelength	R	R													
d. Extinction coefficient (obscurant)	R	R													
e. Reflectivity (tgt/bkg)	R	R													
f. Beam diameter															
g. Beam divergence															
h. Pulse rate/shape															
8. External radiation sources	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
a. Coordinates (angular)	R	R	R												R
b. Radiance (at target)	R	R	R												R
c. Radiance (at cloud)	R	R	R												
9. Geographical data			R							R		R			
10. Diurnal/seasonal data			R							R					

TABLE 5b. MISCELLANEOUS

FIELD TEST NAME

	BSC SMOKE	JPG SMOKE	FT SILL SMOKE	WSMR SMOKE	PH IIA SMOKE	PH IIB SMOKE	SMOKE WK I	FOR SMOKE III	SMOKE WK II	H3S SMOKE	PH IIA DUST	DUST/DEBRIS	DIRT I	DIRT II	DIRT III	SMOKE WK III	GRAF II	BELDWSS III
1. Coordinates (delivery system)													D	D				
2. Delivery system data	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
a. Type			D			D	D					D	D	D			D	
b. Maximum range																		
c. Maximum rate/duration																		
d. Precision error																		
e. Aiming error																		
f. Reliability (of round)																		
3. Submunition data	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
a. Submunitions/round																		
b. Fill mass																		
c. Burst height																		
4. Submunition impact pattern																		
5. Volley data	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
a. Aim points			D			D						D	D	D				
b. Ideal impact points/spacings			D	D			D	D	D		D		D	D				
c. Number rounds per volley		D	D			D	D										D	
d. Number of volleys		D	D			D	D										D	
e. Volley rate		D	D			D	D										D	
6. Screening data (a priori)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
a. Height																		
b. Length																		
c. Width																		
d. Duration						NOT APPLICABLE												
e. Formation time																		
f. Fractional coverage																		
g. Available systems (number)																		
h. Available rounds (number)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
7. Laser designator	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
a. Coordinates																		D
b. Intensity																		D
c. Wavelength																		D
d. Extinction coefficient (obscurant)																		
e. Reflectivity (tgt/bkg)																		D
f. Beam diameter																		D
g. Beam divergence																		D
h. Pulse rate/shape																		D
8. External radiation sources	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
a. Coordinates (angular)																		
b. Radiance (at target)																		
c. Radiance (at cloud)																		
9. Geographical data													D	D	D			
10. Diurnal/seasonal data	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D

TABLE 6a. COMPUTATIONAL AND CONTROL

MODEL NAME

	ACT I	HECSOM	SOM II	SMOKE	GRNADE	BURN	FIRE	STILES	SEMM	KWIK	MUNXP	ASL DUST	DIRTRAN	HEDUST	ACT II
1. Starting time	R	O		R	R										R
2. Ending time	R	O		R	R										R
3. Timing increment	R	O		R	R				R						R
4. Number of sources	R	R		R		R			R						
5. Number of sensors						R			R						
6. Adverse weather option	R	R													
7. Source characteristics option		R													
8. Atmospheric model option			R												
9. Infrared scenario option	R	R													
10. Path designation option			R												
11. Diffusion methodology option			R												
12. Impact generator option			R												
13. Laser designator option	R	R													
14. Number of sky sectors	R	O													
15. Number of terrain sectors	R	O													
16. Radius of terrain plane	R	R													
17. Lines of sight boundaries								R							
18. Lines of sight increments								R							
19. Random number seed								R							
20. Scenario replications (number)								R							
21. Observer-target increments	R														
22. Target-background increments	R														
23. Integration points (initial)										R					
24. Integration points (maximum)										R					
25. Integration error (maximum)										R					
26. Receptor distances		O													
27. Number of radiation sources	R	R													
28. Number of targets						R									

TABLE 6b. COMPUTATIONAL AND CONTROL

FIELD TEST NAME

NOT APPLICABLE
TO FIELD DATA

1. Starting time																		
2. Ending time																		
3. Timing increment																		
4. Number of sources																		
5. Number of sensors																		
6. Adverse weather option																		
7. Source characteristics option																		
8. Atmospheric model option																		
9. Infrared scenario option																		
10. Path designation option																		
11. Diffusion methodology option																		
12. Impact generator option																		
13. Laser designator option																		
14. Number of sky sectors																		
15. Number of terrain sectors																		
16. Radius of terrain plane																		
17. Lines of sight boundaries																		
18. Lines of sight increments																		
19. Random number seed																		
20. Scenario replications (number)																		
21. Observer-target increments																		
22. Target-background increments																		
23. Integration points (initial)																		
24. Integration points (maximum)																		
25. Integration error (maximum)																		
26. Receptor distances																		
27. Number of radiation sources																		
28. Number of targets																		

TABLE 7a. OUTPUTS

MODEL NAME

	ACT I	HECSOM	SOM II	SMOKE	GRNADE	BURN	FIRE	STILES	SEMM	KWIK	MUNXP	ASL DUST	DIRTRAN	HEDUST	ACT II
1. Concentration	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
a. Point		X													
b. Path	X	X	X	X	X	X			X			X	X	X	X
2. Dosage	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
a. Point		X													
b. Path		X													
3. Screen dimensions	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
a. Alongwind				X											X
b. Crosswind				X											X
c. Vertical				X											X
4. Cloud centroid				X											X
5. Transmittance	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
a. Visible	X	X	X	X	X	X						X	X	X	X
b. Near infrared	X	X	X	X	X	X						X	X	X	X
c. Mid infrared	X	X	X	X	X	X						X	X	X	X
d. Far infrared	X	X	X	X	X	X						X	X	X	X
e. Millimeter				X											
f. Other															
6. Path radiance	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
a. Visible (photopic)	X	X	X												X
b. Near infrared	X	X	X												X
c. Mid infrared															X
d. Far infrared															X
e. Millimeter															
f. Other															
7. Contrast transmittance	X	X	X												X
8. Probability of detection	X	X	X												
9. Cloud temperature							X								X
10. Particle flux density							X								
11. Screen requirements	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
a. Rounds to establish								X		X	X				
b. Rounds to maintain										X	X				
c. Firing rate										X	X				
d. Aim points											X				
e. Munition spacings								X		X	X				
12. Effective screen length									X		X				

TABLE 7b. OUTPUTS

FIELD TEST NAME

	BSC SMOKE	JPG SMOKE	FT SILL SMOKE	WSMR SMOKE	PH IIA SMOKE	PH IIB SMOKE	SMOKE WK I	FOR SMOKE III	SMOKE WK II	H3S SMOKE	PH IIA DUST	DUST/DEBRIS	DIRT I	DIRT II	DIRT III	SMOKE WK III	GRAF II	BELDWSS III
1. Concentration	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
a. Point					D	D	D	D	D	D	D	D	D	D	D	D		D
b. Path				D	D	D	D	D	D	D	D	D				D		D
2. Dosage	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
a. Point					D	D	D	D	D	D	D	D			D	D		D
b. Path					D	D	D	D	D	D	D	D				D		D
3. Screen dimensions	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
a. Alongwind		D			D	D	D	D	D		D	D	D	D	D			D
b. Crosswind					D	D	D	D	D		D	D	D	D	D			D
c. Vertical		D			D	D	D	D	D		D	D	D	D	D			D
4. Cloud centroids		D												D	D			D
5. Transmittance	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
a. Visible			D		D	D	D	D	D	D	D	D	D	D	D	D	D	D
b. Near infrared			D		D	D	D	D	D	D	D	D	D	D	D	D	D	D
c. Mid infrared			D		D	D	D	D	D	D	D	D	D	D		D	D	D
d. Far infrared			D		D	D	D	D	D	D	D	D	D	D	D	D	D	D
e. Millimeter													D	D	D		D	
f. Other																		
6. Path radiance	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
a. Visible (photopic)					D	D	D	D	D	D	D	D				D		D
b. Near infrared					D													D
c. Mid infrared																		
d. Far infrared																D		
e. Millimeter																		
f. Other																		
7. Contrast transmittance			D							D						D		
8. Probability of detection																	D	
9. Cloud temperature																		
10. Particle flux density	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
11. Screen requirements																		
a. Rounds to establish																		
b. Rounds to maintain																		
c. Firing rate																		
d. Aim points																		
e. Munition spacings																		
12. Effective screen length																		

FIELD TEST NAME

TABLE 8. MUNITIONS/SOURCES (by number of trials)

	BSC SMOKE	JPG SMOKE	FT SILL SMOKE	WSMR SMOKE	PH IIA SMOKE	PH IIB SMOKE	SMOKE WK I	FOR SMOKE III	SMOKE WK II	H3S SMOKE	PH IIA DUST	DUST/DEBRIS	DIRT I	DIRT II	DIRT III	SMOKE WK III	GRAF II	BELDWSS III
SMOKE																		
1. 2.75 in wick, WP				2					2							1		
2. 2.75 in wedge, WP	4																	
3. 3.0 in wick, WP	4																	
4. 6.0 in wick, WP	4																	
5. 60 mm M302, WP		6	4															
6. 81 mm M375, WP		6			3					8								
7. 4.2 in M328, WP				3	3		2											
8. 105 mm M16, WP			3															
9. 105 mm M60, WP		5			3													
10. 155 mm M104, WP		6	2															
11. 155 mm M110E2, WP					3		2											
12. 155 mm XM825 wedge, WP									2	5						3		
13. 82 mm foreign, WP							1	3										
14. 120 mm foreign, WP							1	3	3									
15. 122 mm foreign, WP							1	3	1							1		
16. 130 mm foreign, WP							1	3										
17. 81 mm navy wedge, RP	4																	
18. 81 mm German wedge, RP	4																	
19. 155 mm navy wedge, RP	4																	
20. 155 mm XM803 wedge, RP									2									
21. L8A1 grenade M239, RP						4	2			6						1		698
22. L8A1 grenade M243, RP						4												
23. 4.2 in M2 projectile, PWP		8	1	3	3													
24. 5.0 in zuni M54, PWP									2							2		
25. 105 mm M84 cannister, HC	4	4			3		2											
26. 105 mm M84 projectile, HC			3															
27. 155 mm M1 canister, HC	4									8						3		
28. 155 mm M2 canister, HC	4																	
29. 155 mm M104 canister, HC									2									
30. 155 mm M116 canister, HC		6			3													
31. 155 mm M116 projectile, HC			3															
32. M5 smoke pot, HC				2	1													
33. M3A3 SGF, fog oil									2							2		306
DUST																		
34. C4/TNT 105 mm simulated, HE									3		1							
35. C4/TNT 155 mm simulated, HE									2		1					2		

TABLE 8. MUNITIONS/SOURCES (cont)

FIELD TEST NAME

	BSC SMOKE	JPG SMOKE	FT SILL SMOKE	WSMR SMOKE	PH IIA SMOKE	PH IIB SMOKE	SMOKE WK I	FOR SMOKE III	SMOKE WK II	H3S SMOKE	PH IIA DUST	DUST/DEBRIS	DIRT I	DIRT II	DIRT III	SMOKE WK III	GRAF II	BELDWSS III
36. TNT 81 mm simulated, HE											1							
37. TNT 4.2 in simulated, HE											1							
38. TNT 120 mm simulated, HE											1							
39. TNT 8 in mm simulated, HE											1							
40. 105 mm M107 projectile, HE												11		27	9			
41. 155 mm M1 projectile, HE												9	18	30	9			
42. C4/TNT (various)													18	12	53			52
43. 4.2 in projectile, HE														11				
OTHER																		
44. M48 tank dust									2									
45. Vehicular dust (various)												4				1		154
46. Burning hulk									2									
47. Oil, rubber, diesel fuel fire													1					82
48. Experimental smoke									6							18		
49. 122-mm projectile, HE															9			
50. 152-mm projectile, HE															8			
51. XM49, 0.1 smokes																5		
52. CBU-88, RP																2		
53. M8 grenade, RP																1		
54. Canisters, HC (various)																		184

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APPENDIX

DEFINITIONS

This appendix contains definitions for each numbered input or output quantity used in tables 1a through 7b. The numbering scheme used here is consistent with that used in the tables. For example: WINDSPEED, listed as definition 1.1, also appears on table 1 as item 1; WIND DIRECTION, listed as definition 1.2, corresponds to table 1, item 2; and COORDINATES (definition 2.1) corresponds to table 2, item 1. The numbers here should not be confused with section numbers.

1.1 WINDSPEED: The time rate of transport (in the horizontal plane) of the ambient air. Windspeed is usually a highly fluctuating quantity required in the models as a time mean. That is:

$$\bar{U} = \frac{1}{N}\sum_{i}\left[u_{x,i}^2 + u_{y,i}^2\right]^{1/2} \qquad (1\text{-}1)$$

where $u_{x,i}$ and $u_{y,i}$ are instantaneous values along the two horizontal axes of a coordinate system designating x-east, y-north, and z-upward (figure A-1).

Windspeed and wind direction (see below) are usually measured simultaneously at the same location with standard vanes and cup anemometers which measure the summand of equation (1) directly. Other instruments such as "uvw" anemometers and bivanes measure the vector components.

1.2 WIND DIRECTION: The direction from which the wind is blowing referring to the upwind (also called windward) direction. The associated wind vector is the direction toward which the wind is blowing referring to the downwind (also called leeward) direction. Both wind direction and wind vector are referenced positive clockwise from North; for example, a west wind has wind direction 270° and wind vector 90°.

Strictly, the wind vector azimuth and elevation are defined as:

$$\bar{\theta}_A = \arctan(\bar{u}_x/\bar{u}_y) \qquad \text{azimuth}$$

$$\bar{\theta}_E = \arctan(\bar{u}_z/\bar{U}) \qquad \text{elevation} \qquad (1\text{-}2)$$

where the overbars refer to time averages in the fixed x, y, and z system of figure A-1 and $\bar{U}$ is the mean windspeed defined above.

1.3 STANDARD DEVIATIONS - (WINDSPEED, AZIMUTH AND ELEVATION): The standard deviations of the temporal fluctuations of the various wind components about the mean.

The measurements are usually referred to a coordinate system rotated to align the positive absissa along the mean wind vector as sketched in figure A-1.

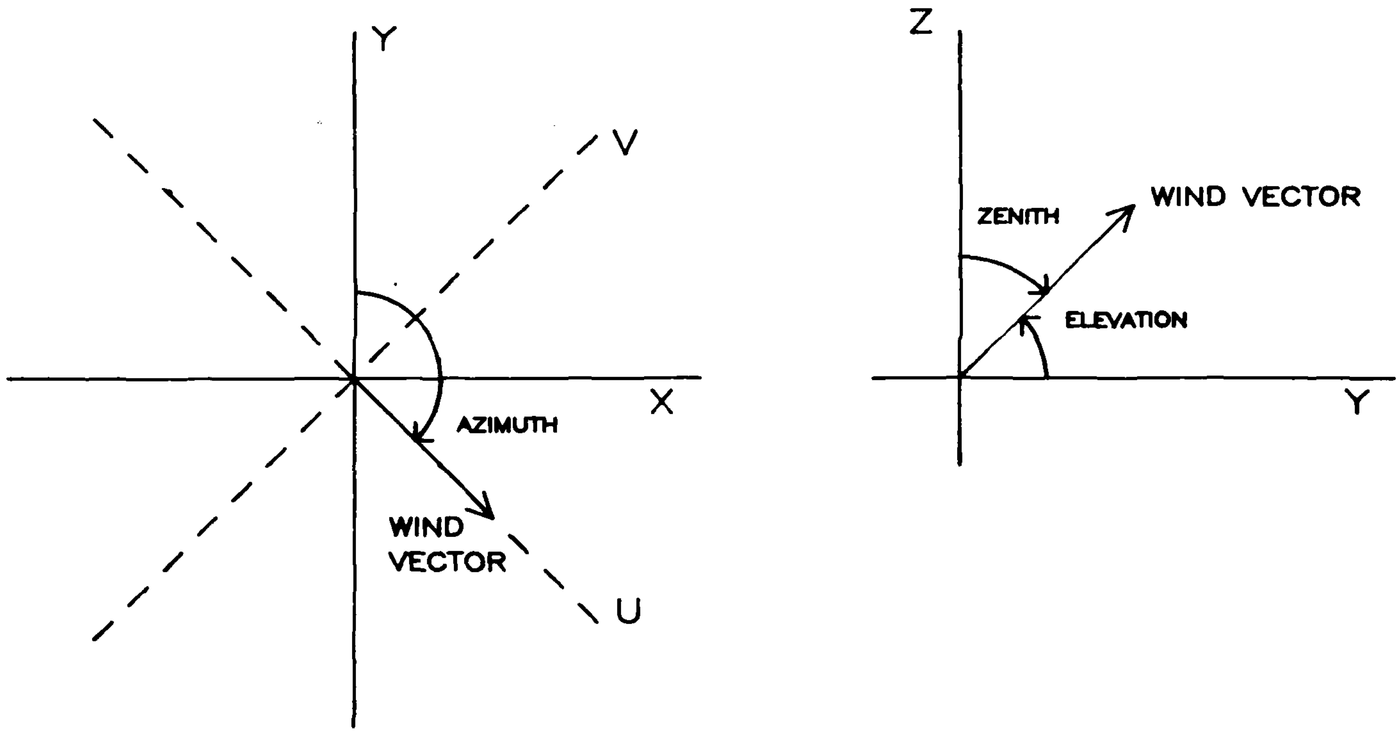

Figure A-1. Sketch demonstrating the relationships between the fixed x,y,z coordinate system and the wind vector aligned u,v,w coordinate system.

Standard deviations then refer to the alongwind (u), crosswind (v), and vertical (w) fluctuating components as:

$$u' = u - \overline{u}$$
$$v' = v - \overline{v} \qquad (1\text{-}3)$$
$$w' = w - \overline{w}$$

so that the standard deviations become:

$$\sigma_u^2 = \overline{u'^2}$$
$$\sigma_v^2 = \overline{v'^2} \qquad (1\text{-}4)$$
$$\sigma_w^2 = \overline{w'^2}$$

where the overbars again refer to time averages.

In the rotated system $\overline{v} = 0$, and usually $\overline{w} = 0$, so that for practical cases the wind azimuth and elevation standard deviations are given by:

$$\sigma_A = \frac{\sigma_v}{\overline{u}}$$
$$\sigma_E = \frac{\sigma_w}{\overline{u}} \qquad (1\text{-}5)$$

To be useful in modeling it is critical that sampling rates and averaging times (definition 1.9) also be specified in reporting this type data.

1.4 POWER LAW EXPONENT (WIND): A parameter used to estimate the vertical gradient of the mean windspeed, defined by the following power function:

$$\overline{U}(z) = \overline{U}(z_r)x(z/z_r)^{\alpha} \qquad (1\text{-}6)$$

where z_r is some arbitrary, but specified, reference height and α is the <u>power law exponent</u>.

1.5 GRADIENT (wind azimuth): The rate of change of the mean wind vector azimuth with respect to height. Models surveyed here assume the gradient constant, but some (later) models report to require a power law exponent analogous to item 1.4 above.

1.6 TEMPERATURE (ambient): The mean ambient air temperature, usually assumed constant over the horizontal extent of the trial grid but variable in the vertical.

1.7 Gradient (temperature): The rate of change of the mean ambient air temperature with respect to height, usually calculated from measurements at several different heights. The gradient is a strong function of height, especially near the surface; however, a somewhat standard working definition has emerged from the Smoke Week data base as:

$$GRAD_T = \frac{T(8m) - T(0.5m)}{7.5m} \qquad (1\text{-}7)$$

For a lapse condition (temperatue decreasing with height) the gradient is negative, and for an inversion (temperature increasing with height) the gradient is positive. This convention and the division by the vertical separation are not always followed in test reporting, however, and can lead to confusion.

Some models require the gradient of potential temperature, which is obtained by subtracting the adiabatic lapse rate (-0.00966°C/m for dry air).

1.8 REFERENCE HEIGHTS: The height(s) above the surface at which wind and temperature measurements are made. Unless otherwise specified, both are assumed to be measured at 2 m above the surface.

1.9 SAMPLING RATE/TIME: The rate and time interval over which fluctuating quantities are averaged. Also, instrument time constants are desired. These quantities are most critical for items 1 through 5 but are desirable for all averaged quantities.

1.10 AIR DENSITY: The mass per unit volume of the ambient air. Air density is usually not measured directly but is computed from the air pressure and temperature using the ideal gas law.

1.11 AIR PRESSURE: The force per unit area exerted by a column of the ambient air. Air pressure can be measured accurately with commercial instrumentation. Some caution is required in using standard weather data, which may be "corrected" for station altitude to give equivalent sea level values, whereas actual air pressure is required for model calculations.

1.12 RELATIVE HUMIDITY: The ratio of the ambient moisture partial pressure to the saturation vapor pressure, usually expressed in percent. This quantity can be measured directly with commercial instrumentation but can also be computed from the ambient air temperature and dew point using standard empirical relationships. Relative humidity is critical in modeling hygroscopic activity in some inventory smokes and in estimating atmospheric transmission and thermal emission (infrared). For relative humidity near 100 percent special techniques are required for high accuracy.

1.13 DEW POINT TEMPERATURE: The temperature at which the ambient atmosphere would be moisture saturated (that is, fog) if cooled at constant pressure and density. The dew point temperature can be computed from the ambient air temperature and the relative humidity using well established empirical relationships.

1.14 MIXING HEIGHT: The mixing (layer) height is strictly defined as the height above which the dynamics of the atmosphere are relatively independent of events or features below, especially with regard to surface effects such as terrain roughness. The atmosphere below this height is often referred to as the "mixed" layer or boundary layer, characterized by strong turbulence, relatively rapid temperature variations, and strong fluxes of momentum and heat.

The significance of the mixing layer height to obscuration modeling is that atmospheric forces tend to keep obscurant clouds confined to the mixed layer. Under conditions of a low mixing height obscurant clouds will usually be confined near the surface. A higher mixing height allows more vertical motion, usually resulting in less obscurant near the surface.

Mixing height can be measured directly by using SODAR (acoustic) techniques, but more accurate determinations require complex considerations involving many meteorological variables obtained (perhaps) from radiosondes.

1.15 INVERSION HEIGHT: The inversion height is a term applied during conditions of a temperature inversion, wherein the temperature increases with height. (Inversions usually occur during stable nocturnal conditions.) The inversion height in these cases can be defined as the height where the potential temperature gradient becomes zero (that is, adiabatic).

1.16 CEILING: The average level of the lower surface of the ambient cloud layer. It is zero for ground fog and infinite (undefined) for a cloudless day.

1.17 CLOUD COVER: The percentage of the upper (sky) hemisphere obscured by clouds.

1.18 NET RADIATION: The net flux of radiant energy measured very near the surface (see also ambient radiation, item 3.1). Net radiation can be directed either toward (positive, usually daytime) or away from (negative, usually nighttime) the surface. Strictly, this measurement refers to radiant flux integrated over all wavelengths but in current meteorological jargon is referred to as "short" wave (visible and near infrared) or "long" wave (mid and far infrared). Measurements of both can be obtained routinely with standard instruments.

The significance of the net radiation to obscuration modeling is twofold: (1) the net radiation has a strong influence on other meteorological quantities, such as the mixing height, the inversion height, and the stability; and (2) the net radiation serves as a good indicator of the ambient irradiance, or light level, used in contrast and target acquisition modeling.

1.19 VISIBILITY: The term "visibility" refers to the horizontal distance beyond which an observer can no longer distinguish an object/background of some assumed contrast. In the past the determination of this quantity has been based wholly upon human observation and judgment. More recent attempts have been made to establish an exact definition based upon the Koschmieder equation relating visibility to an instrumentally measured volume extinction coefficient as:

$$V = 3.912/\sigma \tag{1-8}$$

The modern definition, although offering the advantage of objectivity, is sometimes less preferred because the determination of σ is made at a single point rather than over an actual line of sight. For a homogeneous atmosphere, however, the two are theoretically equivalent.

Visibility is very important in atmospheric electro-optical modeling, in that it is the one quantity that best indicates how well one can "see" through the ambient atmosphere (visible wavelengths only). It is of added significance, however, in that other variables, such as infrared transmission and rain rate, are derived from empirical relationships using visibility as the "independent" variable.

1.20 STABILITY CATEGORY: The term stability can be defined as a parameter specifying the degree to which the atmosphere will react to externally induced perturbations. This property is strongly linked to such vertical profiles as temperature, wind, and humidity, and to such surface characteristics as roughness, temperature, and emissivity. On a given day the degree of the stability of the atmosphere is determined by many other factors, such as windspeed, net radiation, and sensible heat flux, and is itself not subject to direct measure.

The scheme used most often for determining stability is the Pasquill-Gifford-Turner (PGT)[1] method, which ranks stability in six basic regimes (or categories) labeled (A) through (F) (or sometimes 1 through 6), leading from extremely unstable (A) to extremely stable (F). Category D signifies neutral.

The significance of atmospheric stability to obscuration modeling is that an unstable atmosphere will disperse an obscurant more than a stable atmosphere will. Also, both turbulent intensities and upward bouyant motion are enhanced during unstable conditions.

The concept of a stability category scheme may be challenged by some transport and diffusion modelers who sometimes prefer a quantitative measure such as the Richardson number. This criticism may be justified. However, much like visibility, the stability category has come to serve as a single parameter from which many other parameters are empirically inferred and should be included in any reporting of test data.

1.21 ADVERSE WEATHER: Set of codes and/or data specifying the type, vertical extent and volume extinction coefficient (km^{-1}) of the atmosphere in the presence of adverse weather. The models surveyed assume the adverse weather to be uniform over the scenario extent.

1.22 PRECIPITATION: More strictly, the precipitation intensity, referring to the time rate of accumulation at the surface of precipitating moisture. Some models also require a precipitation type code (indicating rain, snow, hail, etc.) and a descriptive estimate of intensity (light, heavy, etc.). Measurements are usually quantitative (that is, millimeters per hour). Models using descriptive estimates assume the precipitation to be constant in both space and time. Qualitative estimates are based upon visibility according to the following scheme:

Visibility	Description
<1.0 km	light
0.5 to 1.0 km	moderate
>0.5 km	heavy

1.23 RADIOSONDE DATA: A set of standard measurements consisting of temperature, pressure, humidity and winds aloft, recorded from instruments aboard an ascending (or descending) weather balloon. These measurements, although not directly required by most models, are nevertheless useful for computing other required data, such as mixing height, ceiling, stability, atmospheric transmission and emission.

[1]F. Pasquill, 1974, Atmospheric Diffusion, Wiley and Sons, New York, NY.

1.24 COORDINATES: Generally, the Cartesian coordinates and/or polar angles specifying the locations of all scenario elements, including meteorological sensors, optical receivers, and targets, but here referring only to the meteorological elements. In most models any convenient right-handed coordinate system is adequate, provided that either the angular position of the north vector or the heading of the x (or y) positive axis is specifed (figure A-2). A single coordinate system should be used in specifying the locations of all scenario elements, including sensors, munitions, targets, and radiation sources. When only the direction is practical, polar angles are used to specify azimuth and elevation angles: azimuth is referenced positive clockwise from north and elevation is referenced positive upward from the horizon. Sometimes the zenith angle, referenced positive downward from the zenith, is used in place of elevation. For complete specification of the scenario, some reports also include terrain/elevation maps of the site and surroundings, or at least elevation along the sampling lines.

The sketch of figure A-2 demonstrates a typical scenario reference system. For most models the exact coordinate alignment can be arbitrary, however, convention normally dictates a right-handed system with y axis usually to the north and x axis to the east.

1.25 TIME SERIES DATA: The time series record of all data. Usually models only require time data to be referenced to some "starting" time for each trial event, but report data should give the Greenwich Mean Time (Gmt) (also known as Universal Coordinated Time [UCT] or as "Zulu" time).

2.1 COORDINATES (sources): The Cartesian coordinates and/or polar angles specifying the locations of all obscurant sources as described in item 1.24. Source here is distinguished from the sensor target (4.10).

2.2 EVENT TIME: The time(s) of detonation of each source in the scenario. Most models require time (usually in seconds) measured with respect to some specified reference time. For data reporting, scenario events are usually required in Gmt.

2.3 MUNITION TYPE: In models, an arbitrary alphanumeric code to denote a particular munition type, from which many source characteristics are then inferred. In test reporting the minimum required information is the military nomenclature, although both qualitative and quantitative descriptions are highly desirable, especially for special mixes and developmental sources and munitions.

2.4 FILL MASS: For smokes, the total mass of the munition fill, including any catalysts, fillers, or substrates, but not including container, shell or canister mass.

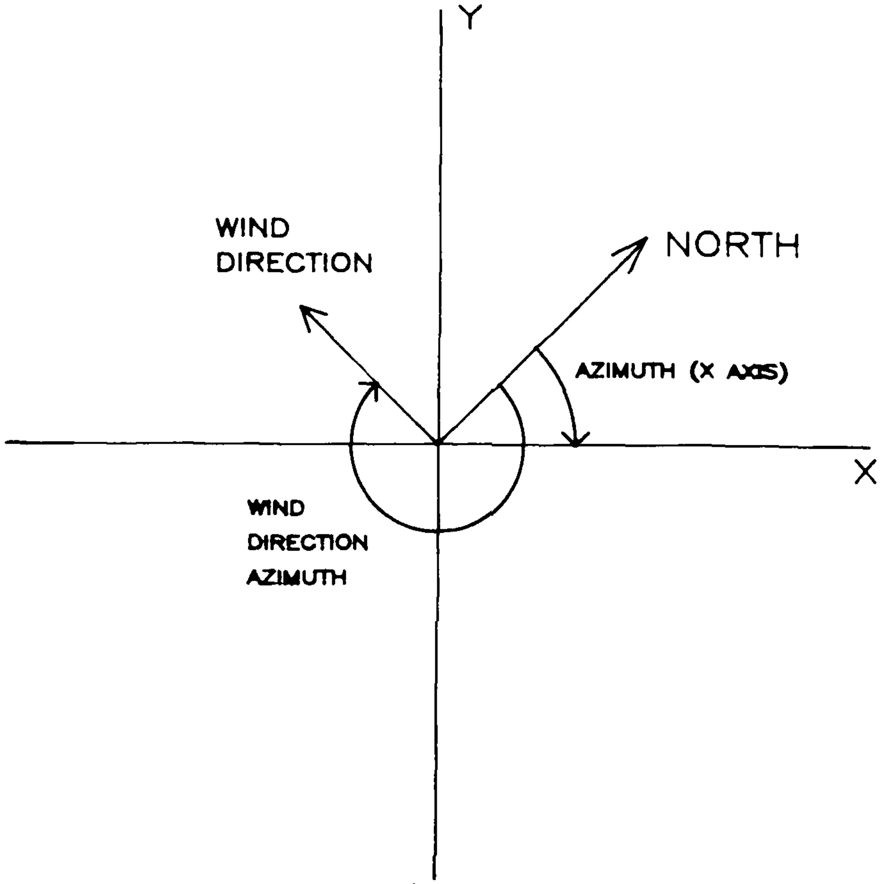

Figure A-2. Typical coordinate scheme for reporting scenario element locations.

2.5 EFFICIENCY: The ratio of the mass of aerosolized material that originated in the munition fill to the total fill mass. Efficiency is dimensionless, ranging in magnitude from 0 to 1. The product of efficiency times fill mass is sometimes referred to as "effective" fill mass.

2.6 YIELD FACTOR: The ratio of the total mass of the aerosolized obscurant to the effective fill mass (see item 2.5). This quantity accounts for increased mass produced by chemical and hygroscopic interactions with the ambient atmosphere and is generally a function of the meteorological conditions, especially relative humidity. In most models the fill mass, efficiency, and yield factor combine to give the total mass of a resultant smoke cloud as:

$$\text{CLOUD MASS} = \text{FILL MASS} \times \text{EFFICIENCY} \times \text{YIELD FACTOR} \quad (2\text{-}1)$$

Not all models use the efficiency or yield factor exactly as defined here. However, regardless of individual definitions, the product of equation (2-1) is generally intended to give the total mass of the cloud. An exception is the SEMM model, which includes removal by buoyant "pillaring" into the definition of efficiency.

Strictly, the definition given here is consistent with that of the Chemical Systems Laboratory[2] if the yield factor is taken to be the "intrinsic" yield factor. Also, the definition of efficiency is consistent if expressed in terms of both "intrinsic" and "overall" yield factor[2] as:

$$\text{EFFICIENCY} = \frac{\text{INTRINSIC YIELD FACTOR}}{\text{OVERALL YIELD FACTOR}} \quad (2\text{-}2)$$

2.7 EMISSION RATE/DURATION: The time rate of production of obscurant mass, sometimes called the "burn function."

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[2]T. L. Tarnove, 1980, Studies of the Chemistry of the Formation of Phosphorus-Derived Smokes and Their Implications for Phosphorus Smoke Munitions, ARCSL-TR-80049, Chemical Systems Laboratory, Aberdeen Proving Ground, MD

For smokes the emission rate is most often modeled by assuming either a quadratic or exponential time function for the production of total accumulated mass as:

$$\text{CLOUD MASS}(t) = \text{CLOUD MASS}\ (t = t_b) \times F(t) \qquad (2\text{-}3)$$

where

$$F(t) = A(t/t_b) + B(t/t_b)^2 + C(t/t_b)^3 + D(t/t_b)^4 \qquad (2\text{-}4)$$

or:

$$F(t) = A(1 - e^{-Bt/t_b}) + C(1 - e^{-Dt/t_b}) \qquad (2\text{-}5)$$

where t_b is the sensible time duration of the production of mass, often called "burnout time" or simply "burn time" and A, B, C, and D are empirically determined constants which are tabulated for some inventory munitions.

2.8 CLOUD BUILD-UP TIME: An estimate of the increment of time needed for cloud dimensions to reach a quasi-steady level.

2.9 SOURCE SIGMAS: Parameters used to estimate the initial dimensions of an obscurant cloud. In most models these are required as standard deviations (alongwind, crosswind, and vertical) of an assumed Gaussian mass distribution representing the cloud at the instant (~ 1 s) following "burnout."

2.10 EQUIVALENT TNT YIELD: An explosive factor based on the equivalent mass of TNT required to produce the same explosive effect as that of a given munition.

2.11 HYDRO-YIELD: The fraction of thermal energy produced by a high-explosive munition which contributes to buoyancy in the main cloud. This parameter is optional and will be fixed in final model versions. It is difficult (if not impossible) to measure directly.

2.12 CHARGE ORIENTATION: The elevation angle of the lateral axis (that is, along the length) of a round at the time of detonation. The round is assumed to be pointing downward for a positive elevation angle.

2.13 DEPTH OF CHARGE: The depth of the center of mass of an HE munition at the time of detonation. Depth is specified as either positive (below the surface) or negative (above the surface).

2.14 APPARENT CRATER VOLUME: The actual measured crater volume. The term "apparent" is used to signify that compaction and fall back has not been taken into consideration. The total lofted mass forming the initial cloud is assumed to be some fraction (called the "actual lofted fraction") of the apparent crater volume times the in situ soil density within the model. Ultimately, soil characteristics and munition placement will be used to predict this quantity.

2.15 CRATER SCALING FACTOR: A scaling parameter used to model explosive shock, defined empirically as:

$$\text{CRATER SCALING FACTOR} = V_a W^{-1.111} \qquad (2\text{-}6)$$

where V_a is the apparent crater volume and W is the equivalent mass (in pounds of TNT). This factor can also be estimated from shock mechanics in cases where the apparent crater volume is unknown. Again, this factor is user-accessible only until the model is finalized.

2.16 BUOYANT/NONBUOYANT MASS RATIO: The fraction of the mass of the dust entrained in the buoyant fireball (HE munitions) to the mass in the nonbuoyant skirt.

2.17 CARBON EMISSION FACTOR: The mass of carbon produced by an HE explosion per unit mass of TNT yield.

2.18 SHAPE FACTORS: Geometrical scaling parameters relating actual cloud dimensions to those of an equivalent sphere. That is:

$$R_T = C_T R \quad \text{alongtrack}$$

$$R_P = C_P R \quad \text{crosstrack}$$

$$R_V = C_V R \quad \text{vertical} \qquad (2\text{-}7)$$

where R is the radius of the equivalent sphere, R_T, R_P, and R_V are the modeled cloud dimensions and C_T, C_P, and C_V are the shape factors.

2.19 HEAT YIELD: The total (heat) energy produced by exothermic obscurants or, for some models, the time rate of heat release. Units are normally calories per gram or calories per second (rate).

2.20 INITIAL CLOUD TEMPERATURE: The initial (that is, time = 0) mean temperature of a unit volume of obscurant, including entrained air. Temperature is required at a single specified reference height near to and centered vertically over the source.

2.21 INITIAL EMISSION VELOCITY: The initial (that is, time = 0) mean upward velocity of obscurant particles. Emission velocity is required at a single specified reference height near to and centered vertically over the source.

2.22 PARTICULATE BULK DENSITY: The mass density of the actual obscurant particles taken alone. The measure is also numerically equal to the particulate specific gravity when expressed in grams per cubic centimeter. Bulk density should not be confused with particulate mass concentration (see equation (2-14) in item 2.27).

2.23 INDICES OF REFRACTION: A fundamental optical property of a medium, consisting of a real and imaginary part as:

$$m = n - ik \tag{2-8}$$

where the real part (n) determines the degree of refraction (that is, scattering) in the medium and the imaginary part (k) determines the degree of absorption. In dust modeling this quantity specifies the type(s) of minerals within the soil for optical property computations.

2.24 MASS EXTINCTION COEFFICIENT: A fundamental optical property of a medium, defined as a measure of the degree of attenuation (or extinction) of radiant energy propagating through that medium. Units are based upon extinction per unit length per unit mass density, or square meters per gram.

The mass extinction coefficient is commonly used to compute the amount of radiation which traverses a medium as:

$$I/I_0 = \exp(-\alpha CL) \tag{2-9}$$

where I/I_0 is the ratio of transmitted to incident radiation (also called transmission), CL is the obscurant concentration integrated along the path of propagation and α is the mass extinction coefficient.

The mass extinction coefficient is a measure of the total (scattering plus absorption) extinction and can generally be written as the result of the sum of two parts as:

$$\alpha_{ext} = \alpha_{sct} + \alpha_{abs} \qquad (2\text{-}10)$$

where the two components are due to scattering and absorption, respectively.

The mass extinction coefficient is usually a strong function of both the wavelength and (for hygroscopic smoke) the ambient relative humidity.

2.25 SINGLE SCATTERING ALBEDO: A fundamental optical property of a medium, defined as the ratio of scattering to (total) extinction. This can be written in terms defined in 2.24 as:

$$\bar{\omega}_0 = \frac{\alpha_{sct}}{\alpha_{ext}} \qquad (2\text{-}11)$$

2.26 MIE SCATTERING FUNCTION: A function generally intended to describe the angular scattering properties of a medium, indicating the relative amounts of radiation scattered in a particular direction.

The most general formulation is based upon the phase function, which can be computed exactly (assuming spherical particles) if the particulate bulk density, index of refraction, and particle size spectrum (see item 2.27) are known.

The phase function is readily available from standard "Mie Codes" and has come to be a standard formulation for the scattering function in the contemporary literature.

Unfortunately, the models surveyed here (with the exception of ACT II) require an older formulation using "scattering fractions" based upon particulate number density and scattered intensity (see item 2.27) rather than particulate mass concentration and scattered radiance. This causes some conceptual difficulties when comparing methodologies for different models, especially for a nonuniform particle size spectrum. However, it has been shown[3] that for a given particle size spectrum the phase function and scattering fractions, although conceptually different, are related by a single normalization factor.

Specifically, the phase function [P(θ)] as defined in reference 3 is normalized such that:

$$\frac{1}{4\pi} \int_{4\pi} P(\theta) d\Omega = \bar{\omega}_0 \tag{2-12}$$

where, as before, $\bar{\omega}_0$ is the single scattering albedo.

On the other hand, the scattering fractions [S(θ)] are normalized such that:

$$\frac{1}{4\pi} \int_{4\pi} S(\theta) d\Omega = \bar{\omega}_0 \, \alpha_{ext} \tag{2-13}$$

Some caution is required in converting phase function to scattering fractions, since the underlying particle size spectrum must be known (see discussion in item 2.27).

2.27 PARTICLE SIZE SPECTRUM: A function or set of data generally intended to specify the number density of particulates as a function of particle radius. The particle size spectrum is needed in order to estimate the optical properties of a medium. The particle size spectrum is particularly essential in modeling the wavelength dependence of extinction and scattering.

Actual in situ measurement of the particle size spectrum is at best difficult, and measurements can be in error up to factors on the order of two; however, the shape (that is, the functional form) of the spectrum should be considerably more accurate.

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[3]A. Miller et al, 1978, Studies on the Development of Algorithms for the Prediction of Time Dependent Optical Properties of Aerosols, Contract Report under Contract DAAD07-78-C-0083, US Army Atmospheric Sciences Laboratory, White Sands Missile Range, NM

The total number density and the total mass concentration can be computed from the particle size spectrum as:

$$N = \int_0^\infty n(r)dr$$

$$C = \rho\ (4\pi/3) \int_0^\infty n(r)dr \qquad (2\text{-}14)$$

where ρ is the particulate bulk density.

In actual practice it is usually more accurate to renormalize the particle size spectrum from independent measurements of either N or C rather than to use computed values per se. Also, actual data are usually fitted to some a priori assumed functional form which tends to smooth the data. In models it is usually the parameters from this functional form that are most useful. Some standard functions[4] often used are log normal, Gaussian, Deirmedjian, Junge, and Power Law.

2.28 SIZE FRACTIONS: Parameters used in a scheme to model a varied mix of particle size functions. The scheme is also used to model particle settling, wherein larger particles tend to fall out of the cloud. Thus, the model must compute locations of particles in several size ranges.

3.1 AMBIENT RADIATION: A qualitative term generally intended to stand for any one of the following quantities:

1. Radiance refers to the radiant flux density (energy/area x time) per unit solid angle incident upon a surface with outward normal in the direction of the source (that is, on a plane perpendicular to the direction of propagation) (figure A-3). Units are normally watts per square meter per steradian.

2. (Beam) irradiance refers to radiance integrated over a particular angle, perhaps the solar disc for solar irradiance.

[4]M. Kerker, 1969, The Scattering of Light, Academic Press, New York and London

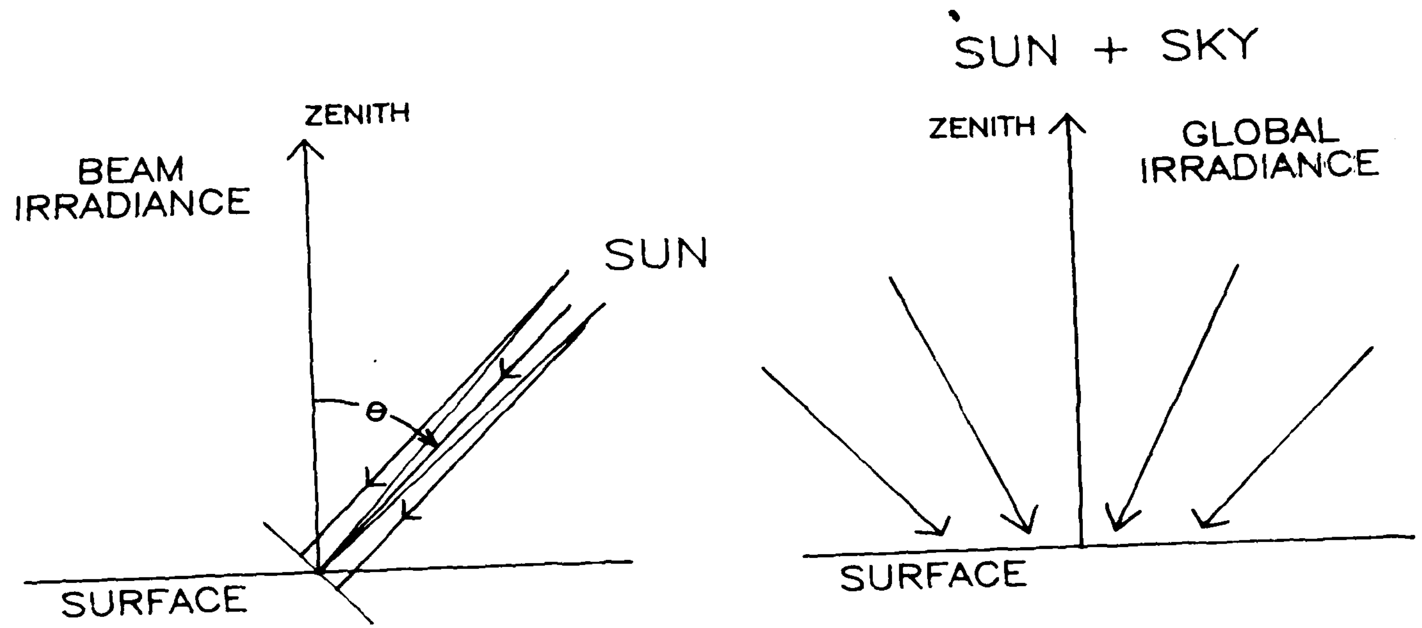

Figure A-3. Sketch demonstrating the definitions of (solar) beam irradiance and global irradiance.

Ordinarily radiance is conceptually viewed as radiation emanating from some source and irradiance as incident upon some surface. Mathematically, radiance (R) and irradiance (E) are related as:

$$E = \int_{\Delta\Omega} R \cos\theta \, d\Omega \qquad (3\text{-}1)$$

where Θ is the angle between the surface inward normal and the direction of propagation and $\Delta\Omega$ is the solid angle of interest. Units are normally watts per square meter.

3. (Hemispherical) irradiance refers to radiance integrated over a (2π Sr) hemisphere centered about the surface outward normal.

4. (Vector) irradiance refers to radiance integrated over a full (4π Sr) sphere and is also often referred to as the "net" flux or "net radiation" (as in item 1.18). Defined in this manner, the net flux will be either toward (+) or away from (-) the surface, hence the term vector irradiance.

5. Luminance is conceptually similar to radiance, differing only in that luminance (L) refers to radiance weighted by wavelength according to the spectral response of the human eye. The conversion is done by introducing the lumen, defined by:

$$E_\lambda(\text{lumens}) = P_\lambda \times E_\lambda(\text{watts}) \qquad (3\text{-}2)$$

where P_λ is defined by the curve of figure A-4 which is also known as the photopic response function or photopic filter function.

Luminance is found by integrating over the full response. That is:

$$L(\text{candles/m}^2) = \int_0^\infty P_\lambda \, R_\lambda(\text{watt m}^{-2} \text{ Sr}^{-1}) d\lambda \qquad (3\text{-}3)$$

Units are normally candles per square meter, where 1 candle = 1 lumen/Sr. An older unit is the footlambert ($1/\pi$ candle/ft^2), not to be confused with the footcandle (defined below), which is a measure of illuminance.

6. Beam, hemispherical and vector illuminance are the photopic counterparts of irradiance. Units are normally lumens per square meter or, in the older literature, footcandles (1 footcandle = 1 candle/ft^2).

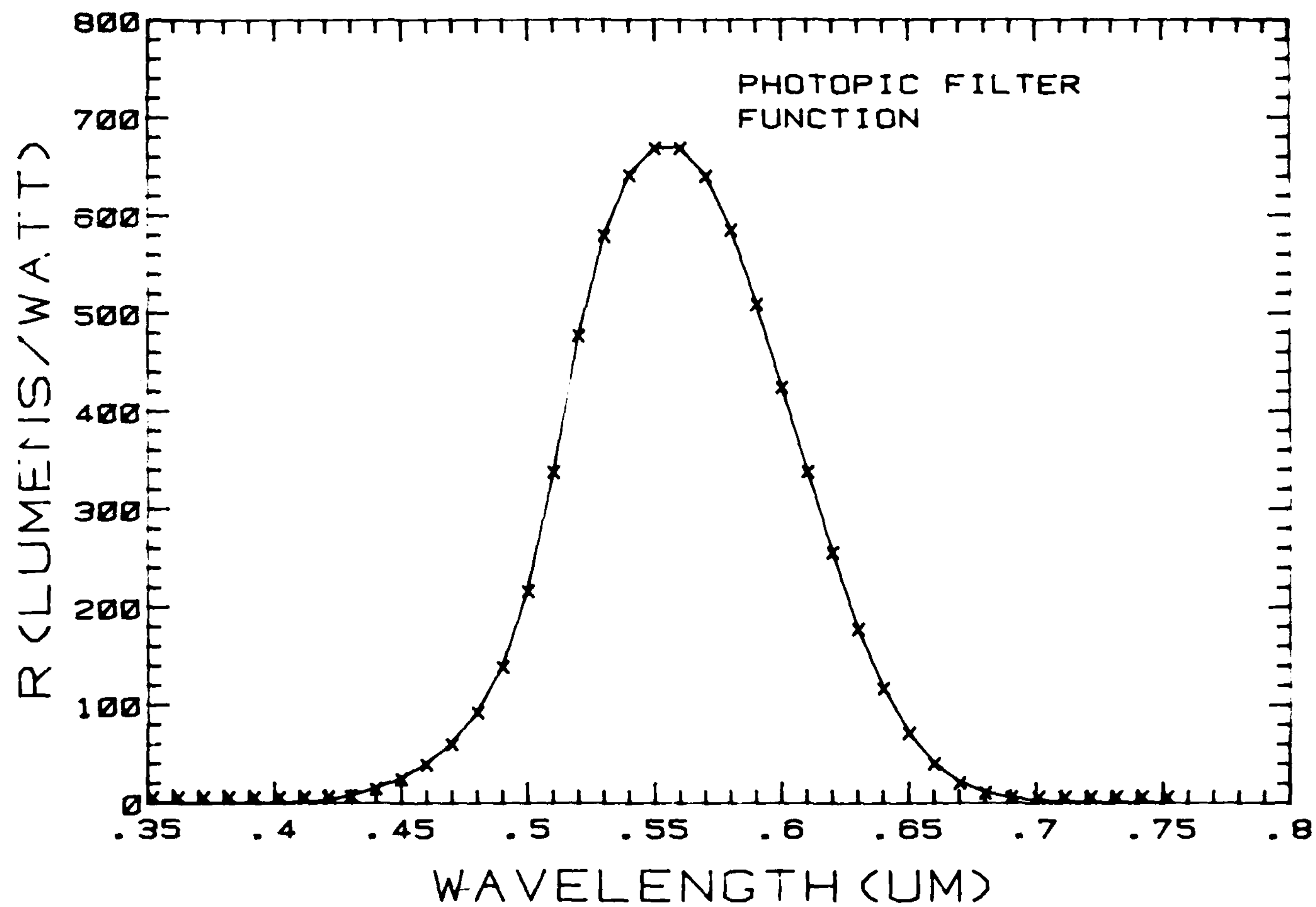

Figure A-4. Spectral response of the human eye, or "photopic" filter function used to convert from radiometric to photopic units.

7. Intensity is strictly defined as energy flux (not flux density) per unit solid angle but is more often used interchangeably with radiance (item 1 above). Modern texts do not as a rule make the distinction between the two, although this can cause some confusion.

8. Brightness strictly refers to the physiological sensation to light of the human eye and has no quantitative definition, although the term is often informally taken as the photopic counterpart of intensity and is probably often confused with luminance.

Models and test data refer to the above quantities in reference to solar, sky, surface, target, and background radiation. The definitions here will be presumed throughout, although not all models or test data are necessarily consistent.

A measurement of special significance, along with the Solar irradiance, is the Global irradiance. Physically, this quantity refers to the total radiant flux density incident upon the earth surface from the totality of the upward hemisphere (sun + sky) and is also referred to variously as Global radiation, insolation or even Solar radiation (in Smoke Week reports). Some texts refer to that portion due to the sky only as diffuse radiation and that due to the sun as direct radiation. The diffuse component can be computed from the sky radiance (see item 3.2) as:

$$E_{sky} = \int_{2\pi} R_{sky} \cos\theta \, d\Omega \qquad (3\text{-}4)$$

where the integration is carried over the entire upward hemisphere (excluding the sun). The Global irradiance is found by adding the solar contribution. That is:

$$E_{global} = E_{sky} + E_{sun} \cos\theta_{zn} \qquad (3\text{-}5)$$

where E_{sun} is the solar (beam) irradiance and θ_{zn} is the solar zenith angle. Units are normally watts per square meter or Langleys per minute where 1 Langley/min = 697 watt/m^2.

3.2 SKY RADIATION: Radiance or luminance from all (for practical purposes, several) directions over the upward (sky) hemisphere, as measured at the surface. A method often used in models for choosing these directions is to divide the sky hemisphere into sectors subtending equal solid angles. In this case, the midpoints of the various sectors (denoted by subscript i) are then given by:

$$\phi_i = (i-1)\pi/m \qquad \text{azimuth}$$

$$\cos\theta_i = 1 - (2i - 1)/2n \qquad \text{zenith} \qquad (3\text{-}6)$$

where m is the desired number of azimuthal sectors and n is the number of zenith sectors.

In Smoke Week data the measurements (when made) are at 4 equally spaced azimuths and 10 equally spaced zeniths, so that some transformation and interpolation is generally needed to make the input compatible with the models.

3.3 TERRAIN RADIATION: Identical in concept to sky radiation defined in item 3.2, except that it refers to the lower (terrain) hemisphere or earth surface.

3.4 SURFACE ALBEDO: Ratio representing the fraction of radiation reflected by a surface to the total amount incident. Also referred to as surface reflectivity. Albedo can be for a particular angle (specular albedo) or, as more likely required, for the whole upward hemisphere (hemispherical albedo). This is a dimensionless quantity ranging in magnitude from 0 to 1.

3.5 SURFACE EMISSIVITY: Ratio representing the fraction of radiation emitted by a surface compared to that of a blackbody at the same temperature. In modeling, the emissivity is used in conjunction with the blackbody function [$B(\lambda,T)$] to compute surface radiance (infrared) as:

$$R(\lambda,T) = \varepsilon\, B(\lambda,T) \qquad (3\text{-}7)$$

where λ is the wavelength, T is (absolute) surface temperature and ε is the emissivity.

Within the scope of the models surveyed the emissivity and reflectivity are related as:

$$\text{EMISSIVITY} + \text{REFLECTIVITY} = 1 \qquad (3\text{-}8)$$

This is a dimensionless quantity ranging in magnitude from 0 to 1. Emissivity, like reflectivity, can be either specular or hemispherical.

3.6 SOIL CHARACTERISTICS: Generally typed according to the relative fractions of sand, clay, silt, and organic matter, indicating the soil texture type. Other significant characteristics are the soil bulk density (see particulate bulk density, item 2.22), the moisture content (usually expressed in percent of wet mass), and the depth of the sod cover.

In DIRTRAN the type is treated as a simple phenomenological parameter indicating desert or European. Eventually, general models (ASL-DUST) will internally or by input use a full description, including perhaps laboratory or in situ measurements of particle size spectrum, compactability, albedo, emissivity, particulate indices of refraction, type of sod, and vegetative cover.

3.7 TERRAIN ROUGHNESS: An aerodynamic parameter influenced by the terrain height, used in models to determine the mean vertical windspeed profile according to the logarithmic law as:

$$\overline{U}(z) = kU_{*} \, Ln(z/z_0) \qquad (3\text{-}9)$$

where k is the von Karman constant (~0.40), U_* is the friction velocity and z_0 is the terrain roughness parameter. The parameter is usually determined from extensive repeated measurements of windspeed at several heights, using equation (3-9) as the defining equation.

3.8 AMBIENT ATMOSPHERE: A model option generally expressed in terms of the nine "standard" atmospheres, giving molecular and aerosol concentration, temperature, pressure and humidity aloft. These data are then used to further model atmospheric transmission and emission via the methodology of the computer code LOWTRAN.[5] Specifically, the nine "standard" atmospheres are indicative of the following general conditions: (1) tropical, (2) midlatitude summer, (3) midlatitude winter, (4) subarctic summer, (5) subarctic winter, (6) 1962 US standard, (7) continental aerosol, (8) rural aerosol, and (9) maritime aerosol.

In most models the use of a standard atmosphere can be omitted by supplying actual radiosonde data or by supplying transmittance data directly.

3.9 REFLECTION COEFFICIENT: A cloud dynamics parameter referring to material reflection at a surface, not to be confused with the optical reflectivity defined in item 3.4. In the models this parameter is used to account for "image" clouds which arise due to particulate reflections at the (earth)

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[5]Selby, J. E., et al, 1978, "Atmospheric Transmittance/Radiance: Computer Code LOWTRAN 4," Environmental Research Papers, No. 626, AFGL-TR-78-0053, Air Force Geophysics Laboratory, Hanscom Air Force Base, MA

surface and due to constraints imposed by the confining effects of a finite mixing height. This is a dimensionless quantity ranging in magnitude from 0 to 1.

3.10 SCAVENGING COEFFICIENT: A parameter used to characterize the time-dependent removal of obscurant from a cloud due to interactions with the underlying terrain or the ambient atmosphere. In models the parameter is used to reduce cloud mass according to a multiplicative exponential factor as $\exp(-\gamma t)$ where γ is the scavenging coefficient.

3.11 ENTRAINMENT COEFFICIENT: A parameter (dimensionless) used to characterize the rate of entrainment of ambient air into an obscurant cloud.

3.12 DRAG COEFFICIENT: A parameter (dimensionless) used to characterize the resistance to motion imposed by a fluid medium upon a moving object. The concept can be applied to the obscurant cloud as a whole, usually in modeling vertical motion, or to the individual particles settling under the influence of gravity. For low Reynolds numbers (low velocity) and well-defined particle shape and size, the coefficient can be computed theoretically.

3.13 SETTLING VELOCITY: The time rate of fall of particulate particles settling downward under the force of gravity.

3.14 DIFFUSION FUNCTION EXPONENTS: A set of parameters used to compute standard deviations ($\sigma_{u,v,w}$) of Gaussian obscurant cloud concentrations as a function of downwind travel distance through relationships of the following general form:

$$\sigma_{u,v,w} = \left[\frac{\bar{U}t + A}{B}\right]^{\alpha} \qquad (3\text{-}10)$$

where $\bar{U}$ is the mean windspeed, t is the time of downwind travel and α is the diffusion function exponent. A (see item 3.15), B (see item 3.16), and the exponents are generally dependent upon source type and atmospheric stability and are different for the alongwind (u), crosswind (v), and vertical (w) directions. These are tabulated in reference 6.

[6]F. V. Hansen, 1979, Engineering Estimates for the Calculation of Atmospheric Dispersion Coefficients, Internal Report, US Army Atmospheric Sciences Laboratory, White Sands Missile Range, NM

Some models (for example, HECSOM) use a slightly different methodology, defining functions of the following general form:

$$\sigma_{u,v,w} = \sigma_w B \left[\frac{\overline{U}t + A - B(1-\alpha)}{\alpha B} \right]^{\alpha} \qquad (3\text{-}11)$$

Still another equivalent but slightly different formulation (BURN, GRNADE) introduces the "reference sigma" as:

$$\sigma_{u,v,w} = \sigma_{ref} \left(\frac{\overline{U}t}{X_{ref}} \right)^{\alpha} \qquad (3\text{-}12)$$

where the functions of the parameters σ_{ref} and X_{ref} are equivalent to those of A and B in equations (3-10) and (3-11).

3.15 DIFFUSION REFERENCE LENGTHS: Diffusion parameters sometimes referred to as "distances from a virtual source," essentially the A parameters of equations (3-10), (3-11), and (3-12). The parameters generally differ for the alongwind, crosswind, and vertical directions.

3.16 DIFFUSION SCALING LENGTHS: Diffusion parameters sometimes referred to as "distances over which rectilinear propagation occurs downwind from a virtual source," essentially the B parameters of equations (3-10), (3-11), and (3-12). The parameters generally differ for the alongwind, crosswind, and vertical directions.

3.17 APPARENT RISE ANGLE: The angle between the upper boundary of a (continuous) obscurant cloud and the horizon. The model (STILES) using this parameter assumes a conical shape for the obscurant cloud.

3.18 HALF WIDTH PARAMETERS: Parameters used with quadradic functions to model the dimensions of a cloud as a function of time. These can be obtained as output from most transport and diffusion models but are used as input for some munition expenditure models (for example, MUNXP).

4.1 COORDINATES (SENSOR): The Cartesian coordinates and/or polar angles specifying the locations of all sensors as described in item 1.24.

4.2 TYPE (SENSOR): In models, an arbitrary alphanumeric code denoting a specific sensor type. No single convention has been developed for this identification, and test data should include relevant specifications, a qualitative description and, if applicable, military nomenclature.

4.3 WAVELENGTH (SENSOR): The optical wavelength(s) over which the sensor operates. Some models, use only the wavelength of maximum sensitivity, but test data should include the entire spectral response of the sensor (see item 4.4). Some models while not requiring wavelength per se, do have an indirect requirement in that the determination of optical properties (for example, extinction and reflectivity) does require wavelength.

4.4 BANDPASS: A term generally intended to stand for some description of the spectral response function of the sensor. Ideally this would be a wavelength by wavelength specification of the instrument sensitivity, as demonstrated by the plot of figure A-5. As a very minimum, test data should include the "full width at half maximum power (FWHM)," or equivalent, as demonstrated in figure A-5.

4.5 THRESHOLD (TRANSMISSION): The assumed transmission below which the sensor cannot attain a given acquisition level (for example, detection, recognition, or identification). In reality, this is generally not a constant and requires specification of target radiance, ambient irradiance, and available contrast for accurate specification. Threshold is usually specified at the 50 percent probability of detection (POD) level.

4.6 THRESHOLD (CONTRAST): The target/background contrast below which the sensor cannot attain a given level of acquisition. Usually given as a function of ambient irradiance (illuminance), it is also dependent upon target/background radiance (luminance).

4.7 THRESHOLD (RESOLVABLE CYCLES): A measure of the degree of resolution required in order for a sensor to attain a given level of acquisition. Resolvable cycles are usually measured in line pairs per unit angle, assuming an equivalent bar pattern to simulate the target (figure A-6). The thresholds of the transmission, contrast, and resolvable cycles are all required to give the ultimate probability of acquisition.

4.8 APERTURE: The cross-sectional area of the sensitive region of a detector or source.

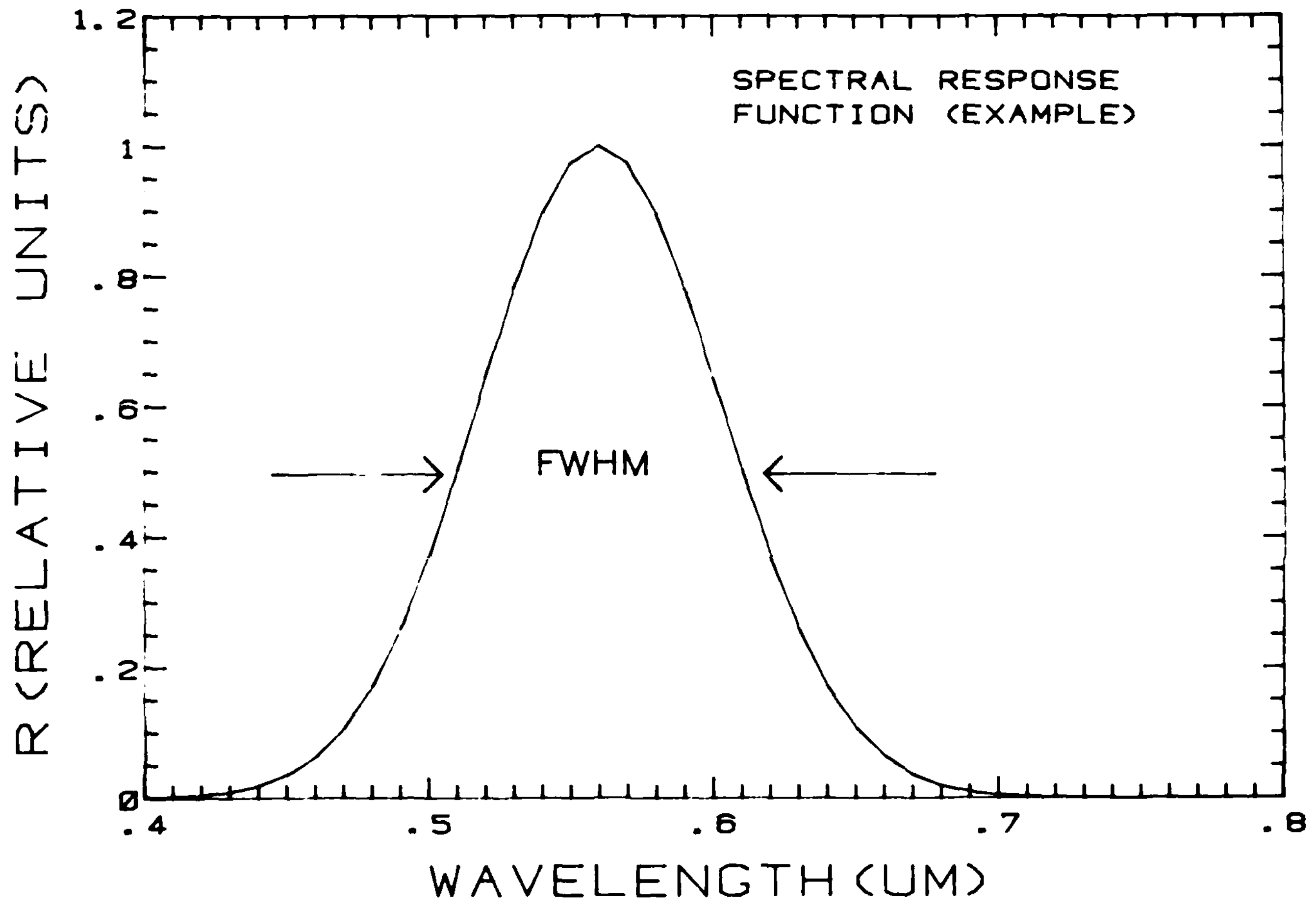

Figure A-5. Example demonstrating the definition of instrument spectral response function and full width-half maximum (FWHM) parameter.

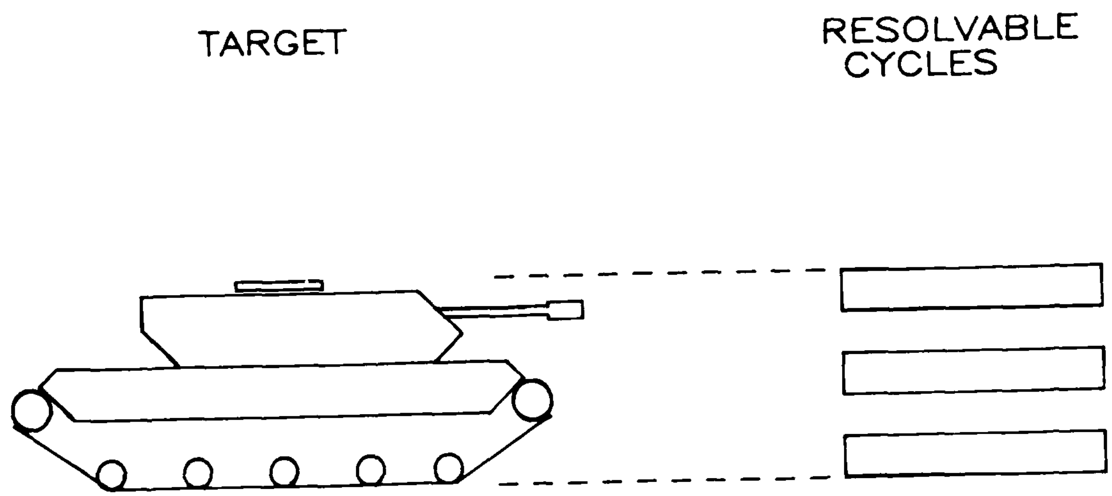

Figure A-6. Sketch demonstrating the concept of target equivalent resolvable cycles.

4.9 FIELD OF VIEW: The angular area (solid angle) over which a detector is sensitive. For scanning devices, both the full field of view (FFOV) and the instantaneous (or "pixel") field of view (IFOV) are required.

4.10 COORDINATES (TARGET): The Cartesian coordinates and/or polar angles specifying the locations of all targets, as described in item 1.24. Target refers to the object or source observed through the obscurant cloud.

4.11 TYPE (TARGET): An arbitrary alphanumeric code used in some models to denote a particular target type. For data bases this requires full description, relevant specifications and, if applicable, military nomenclature.

4.12 EQUIVALENT AREA (TARGET): The cross-sectional area of the target projected on a plane perpendicular to the (given) line of sight.

4.13 MINIMUM DIMENSION (TARGET): The smallest of the projected length, width, or height of the target.

4.14 REFLECTIVITY/EMISSIVITY (TARGET): The reflectivity (or emissivity) of the target, as defined in items 3.4 and 3.5. Wavelength(s) of measurement should also be specified.

4.15 TEMPERATURE (TARGET): Blackbody temperature of the exposed portion of a target, averaged over the detector instantaneous field of view. That is:

$$\bar{T} = (\overline{T^4})^{1/4}$$

where the overbar indicates average over the area of the target encompassed within the sensor IFOV.

4.16 RADIANCE/LUMINANCE (TARGET): Radiance (or luminance) from the direction of the target (item 3.1) assumed to have been measured in the unperturbed (obscurant free) environment. Wavelength(s) should also be specified.

4.17 COORDINATES (BACKGROUND): The Cartesian coordinates and/or polar angles specifying the locations of all background elements, as described in item 1.24. Often, when the target, background and observer are collinear, only the target-background distance needs to be specified.

4.18 TYPE (BACKGROUND): Usually given in test data (Smoke Weeks) as a qualitative description indicating vegetative type and general appearance (color, etc.), mountains, woods, and clear sky.

4.19 REFLECTIVITY/EMISSIVITY (BACKGROUND): Identical to item 4.14 except that it applies to background.

4.20 TEMPERATURE (BACKGROUND): Identical to item 4.15, except that it applies to background.

4.21 RADIANCE/LUMINANCE (BACKGROUND): Identical to item 4.16 except that it applies to background.

4.22 OTHER: A series of model inputs which can be derived from the data above and are included for the convenience of the user.

5.1 COORDINATES (DELIVERY SYSTEM): The Cartesian coordinates and/or polar angles specifying the locations of all delivery systems, as described in item 1.24.

5.2 DELIVERY SYSTEM DATA: *Usually the military nomenclature and a qualitative* description of the delivery system, accompanied by qualitative data such as: the maximum range, the maximum rate of fire and the duration for which the maximum can be sustained. Other significant data include: the round-to-round precision error, the occasion-to-occasion precision error, aiming error, and the reliability of the rounds.

5.3 SUBMUNITION DATA: The number of submunitions per round, the (mean) fill mass of the submunitions and the (mean) burst height of the main munition.

5.4 SUBMUNITION IMPACT PATTERN: Strictly, the point-by-point impact coordinates of all submunitions measured with respect to some central location. Most models accept an alphanumeric code denoting a particular standard pattern, which is then used in either a deterministic or statistical model for source dispersion.

5.5 VOLLEY DATA: General data concerning the deployment and functioning of volleys intended to establish a smoke screen. Data includes the intended center of the volley impact (volley aim points) and the ideal impact points of all rounds in the volley measured with respect to the volley aim point.

In munitions expenditure models (for example, SEMM), these data along with the aiming and precision errors mentioned above, are used to establish a large number of scenario replications using Monte Carlo techniques. The results are then averaged to give "effective" screen dimensions (see item 7.13). Some other required data for simulated scenarios are the total number of volleys fired, the number of rounds per volley and volley rate or time between volleys.

5.6 SCREENING DATA (a priori): These data generally apply to simulations using munitions expenditure models (for example, MUNXP) and represent some added a priori knowledge needed to determine if a specified screen can actually be established under the given restrictions. Requirements (in general) include required length, width, height, and duration in addition to the minimum time allowed for formation and the minimum acceptable percent full coverage (expressed in percent of total required screen frontage).

A priori delivery system data in addition to that already listed are the total number of delivery systems available and the total number of rounds available.

5.7 LASER DESIGNATOR: Applicable for scenarios using laser designator option, this information includes: coordinates, intensity, frequency (or wavelength), obscurant mass extinction coefficient (at laser frequency) and target/background reflectivity (at laser frequency). Additional information from data bases would include: beam diameter, beam divergence, and pulse rate.

5.8 EXTERNAL RADIATION SOURCES: Refers to external radiation sources such as search lights, and flares. Requirements include: angular coordinates and radiance/luminance at surface, target, and top of obscurant cloud.

5.9 GEOGRAPHIC DATA: Miscellaneous data used to specify the geographical location of the scenario, including station latitude, longitude, and altitude. Latitude and longitude are usually specified in degrees north or south of equator (latitude) and degrees east or west of prime meridian (that is, Greenwich).

5.10 DIURNAL/SEASONAL DATA: Miscellaneous data used to specify year, season, and time. Information includes: calendar year, Julian date, month, day of month and time. Time is usually specified as Greenwich mean time (Gmt).

6.1 STARTING TIME: The time for which the first computations are made. All other scenario events are referenced from this time.

6.2 ENDING TIME: The scenario ending time, beyond which no further results are desired.

6.3 TIMING INCREMENT: The increment of scenario time between contiguous (model) computations.

6.4 NUMBER OF SOURCES: Total number of discrete sources to be treated in a given scenario.

6.5 TOTAL NUMBER OF SENSORS: Total number of discrete sensors to be treated in a given scenario.

6.6 ADVERSE WEATHER OPTION: Alphanumeric code denoting that effects of adverse weather are to be treated.

6.7 SOURCE CHARACTERISTICS OPTION: Alphanumeric code denoting whether source characteristics (fill mass, emission rate, etc.) are supplied by the user or by the model.

6.8 ATMOSPHERIC MODEL OPTION: Numerical code denoting one of the nine standard atmospheres for computing atmospheric transmission, or denoting that transmittance data are directly supplied.

6.9 INFRARED SCENARIO OPTION: Alphanumeric code denoting whether model computations are to be carried out in the infrared spectral region (yes or no).

6.10 PATH DESIGNATION OPTION: Alphanumeric code indicating a specified optical path for computations rather than an observer-target/background line of sight.

6.11 DIFFUSION METHODOLOGY OPTION: Numerical code denoting one of four methodologies to be used for modeling transport and diffusion. Standard methodologies are (see SOM II):

Sutton-Calder

Pensyle model

Sloop model

Cramer

6.12 IMPACT GENERATOR OPTION: Numerical code denoting a particular pattern for dispersion of submunitions, to be used in models or for impact of rounds fired in a volley.

6.13 LASER DESIGNATOR OPTION: Alphanumeric code denoting whether target is designated by laser (yes or no).

6.14 NUMBER OF SKY SECTORS: Number of angular sectors used to partition ambient sky radiance.

6.15 NUMBER OF TERRAIN SECTORS: Number of sectors used to partition the angular distribution terrain radiance.

6.16 RADIUS OF TERRAIN PLANE: Radii of equivalent circles in the horizontal plane defining terrain sectors.

6.17 LINES OF SIGHT BOUNDARIES: Extremities of lines of sight termination points, used to examine dimensions of a modeled screen.

6.18 LINES OF SIGHT INCREMENTS: Incremental distance between contiguous lines of sight used to examine dimensions of a modeled smoke screen.

6.19. RANDOM NUMBER SEED: Any arbitrary number used to initiate random number generation for Monte Carlo computations.

6.20 SCENARIO REPLICATIONS (NUMBER): Total number of times scenario is to be replicated to establish statistics of a smoke screen.

6.21 OBSERVER-TARGET INCREMENTS: Linear increments dividing the observer-target line of sight for numerical integrations.

6.22 TARGET-BACKGROUND INCREMENTS: Linear increments dividing the target-background line of sight for numerical integrations.

6.23 POINTS (INITIAL): Initial estimate of number of points needed for integration along line of sight.

6.24 POINTS (MAXIMUM): Maximum allowable number of points for integrations along line of sight.

6.25 INTEGRATION ERROR (MAXIMUM): Criteria for convergency of integration.

6.26 DISTANCES: Distance, along the line of sight, between points for which computations are carried out.

6.27 NUMER OF RADIATION SOURCES: Number of external radiation sources to be treated in the scenario.

6.28 NUMBER OF TARGETS: Number of targets to be treated in the scenario.

7.1 CONCENTRATION: The mass per unit volume of suspended obscurant, sometimes referred to as mass loading. Point-by-point integration over a specified line of sight yields path concentration or "CL" product. Units are normally grams per cubic meter for concentration and grams per square meter for path concentration.

7.2 DOSAGE: Quantity obtained by integrating the cloud concentration over a specified time period, the path dosage also refers to time integrated path concentration.

7.3 SCREEN DIMENSIONS: The spatial extent of an obscurant cloud, usually given in models as Gaussian standard deviations in the alongwind, crosswind, and vertical directions. Test data is usually in the form of photographs or digital imagery.

7.4 CLOUD CENTROIDS: Coordinates of the center points of an obscurant cloud, usually given in terms of alongwind, crosswind, and vertical directions.

7.5 TRANSMITTANCE: Ratio of the radiance which directly traverses a line of sight (unscattered and unabsorbed) to that incident, also referred to as transmission. Radiance transmitted in this way is referred to as direct, as opposed to that which arises by way of scattering, which is referred to as diffuse.

Transmittance can also be expressed in terms of the previously defined mass extinction coefficient (α, item 2.24) and the path integrated concentration (CL, item 7.1) as:

$$T = \exp(-\alpha CL)$$

7.6 PATH RADIANCE: Radiance emanating from an obscurant cloud from a particular direction, which has arisen due to scattering or emission within the cloud. This quantity is also sometimes referred to as diffuse radiation, as opposed to direct, which arises by direct transmission. Units are normally watts per square meter per steradian.

7.7 CONTRAST TRANSMITTANCE: Ratio of (scene) contrast measured at an observer location to that measured at the target-background location. The associated quantity, contrast, is defined at any point as:

$$\text{Contrast} = \frac{R(tgt) - R(bkg)}{R(bkg)}$$

where the radiances (R) include both direct and diffuse components received by an observer from the target-background direction.

In this notation the contrast transmission (T_C) along a path from a target location (X_{tgt}) to an observer location (X_{obs}) is mathematically defined as:

$$T_C = \frac{C(X_{obs})}{C(X_{tgt})}$$

7.8 PROBABILITY OF DETECTION: Probability that a given sensor will detect a given target in (essentially) infinite time. This probability is a strong function of sensor type, target-background type, transmission, available contrast, and ambient radiation.

7.9 CLOUD TEMPERATURE: The mean temperature of a unit volume of obscurant. This includes entrained air and should be distinguished from cloud particulate temperature, which may or may not be the same.

7.10 PARTICLE FLUX DENSITY: In general, the time rate of transport of obscurant particles per unit area, but used here to refer only to the upward direction. A related quantity is the particulate mass flux density, referring to the time rate of transport of particulate mass per unit area.

7.11 SCREEN REQUIREMENTS: The number of rounds, aim points (or spacings) and the firing rate required to establish and maintain a specified smoke screen sufficient to deny a given level of acquisition.

7.12 EFFECTIVE SCREEN LENGTH: The actual length of a smoke screen for which a given threshold is defeated. This definition takes into account "holes" caused by munition placement errors, which are treated by some models. The threshold criteria can be based on direct transmission, contrast tramsmission, or level of acquisition, but in this case refers only to direct transmission.

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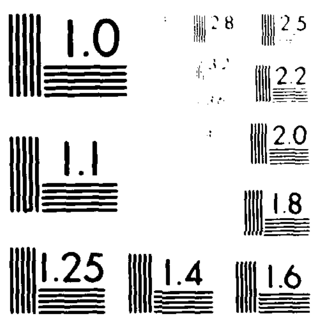

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