PROJECT MANAGER SMOKE/OBSCURANTS
DRCPM-SMK-T
ABERDEEN PROVING GROUND, MD 21005

NOMOGRAPH TECHNIQUES FOR SMOKE/OBSCURANTS SYSTEMS ANALYSIS

by

Eugene B. Boward

OPM SMOKE/OBSCURANTS
TECHNICAL REPORT
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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A nomograph was prepared for solution of Beer's Law to facilitate "Desk Top" approximate estimates of "Smoke vs. Electro-Optical" systems effectiveness. Usage and sample analysis techniques are described and illustrated.

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NOMOGRAPH TECHNIQUES

FOR

SMOKE/OBSCURANTS

SYSTEMS ANALYSIS

BY

EUGENE B. BOWARD

PRODUCT ASSURANCE AND TEST DIVISION

OFFICE OF THE PROJECT MANAGER SMOKE/OBSCURANTS

JULY 1979

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

I. INTRODUCTION

The effectiveness of smoke* that is generated for military screening and obscuration purposes is dependent upon parameters of both the weapon system and its external battlefield environment. This effectiveness is usually measured in terms of the percentage transmittance of light (or other electro-magnetic spectrum) through the cloud - - - the lower the transmittance, the better the obscuring cloud. Weapons parameters having effect upon the smoke's effectiveness are the smoke agent characteristics and the rate at which the agent is disseminated into the atmosphere. Parameters external to the smoke generator that affect the smoke's effectiveness include meteorological conditions (air stability, wind, and relative humidity), distance downwind from the cloud's source, and the terrain.

Mathematical models have been developed and computer-programmed to simulate smoke clouds, for the purpose of predicting the clouds effectiveness (transmittance) against visual and infrared bands of the electro-magnetic spectrum. A number of individuals and organizations are currently involved in improvement of these models. Quantitative results from field tests, such as the Smoke Weeks conducted by PM Smoke, are being used to validate the various model versions. Ultimately, it is expected that these models may be used, in lieu of costly field tests, for much of the evaluation of smoke weapon systems and the electro-optical (EO) systems that the smoke is designed to counter-measure.

The computer-programmed models, with their inherent sophistication and attention to detail, are capable of intensive analyses of "smoke systems versus electro-optical systems." Development of both these systems will benefit from exercise of the models on computers. There are, however, times when individuals who are involved in weapons system development, but who have no access to the programmed models, need an immediate indication of probable performance of their hardware.

One possible solution to this need for immediate approximate indications of smoke systems performance is the use of a nomographic solution of Beer's Law, the generally accepted smoke performance model. This nomograph can provide convenient means for the non-computer oriented personnel to acquire quantitative approximations of "smoke versus electro-optical" system performance.

This report presents a nomograph of Beer's Law, based upon an aerosol diffusion model from ORG-17,** and describes the technique for its usage.

*NOTE: Smoke used throughout to mean Smoke/Obscurants.
**ORG-17: An Edgewood Arsenal publication that included models used by chemical and biological weapon communities.

II. OBJECTIVES

- Describe the nomograph, its basis, and key assumptions.
- Delineate, by illustration, the technique for extracting estimates of "Smoke vs. EO" system parameters and effects, by use of the nomograph and associated calculations.
- Suggest analyses that might be conducted by use of the nomograph.
- Indicate areas where caution is recommended.

III. APPROACH

A. Description of the Model

The nomograph presented herein is a graphical method to permit calculations of downwind responses from ground-level release of various aerosolized smoke agents employed during a variety of meteorological conditions. It is a graphical solution of Beer's Law, which equates transmittance to an exponential function of smoke parameters as follows:

$$T = e^{-\alpha CL}$$

where:

T = Transmittance, the percentage of electro-magnetic energy which will penetrate the smoke cloud.

α = Extinction coefficient, or attenuation coefficient, in units of meter^2/gram. This is an indication of the smoke's ability to block, or absorb, electro-magnetic energy. This coefficient varies with the smoke agent and the particular band of the electro-magnetic spectrum (such as visual, near IR, mid IR, and far IR).

CL = Integral of the smoke concentration, C (gms/meter^3) across the width, L (meters), of the cloud; or the product of average smoke concentration and the cloud width. CL is an indication of the density of the smoke cloud. This CL varies with the initial source strength of the smoke cloud, the downwind distance from the cloud source, and the prevailing meteorological conditions.

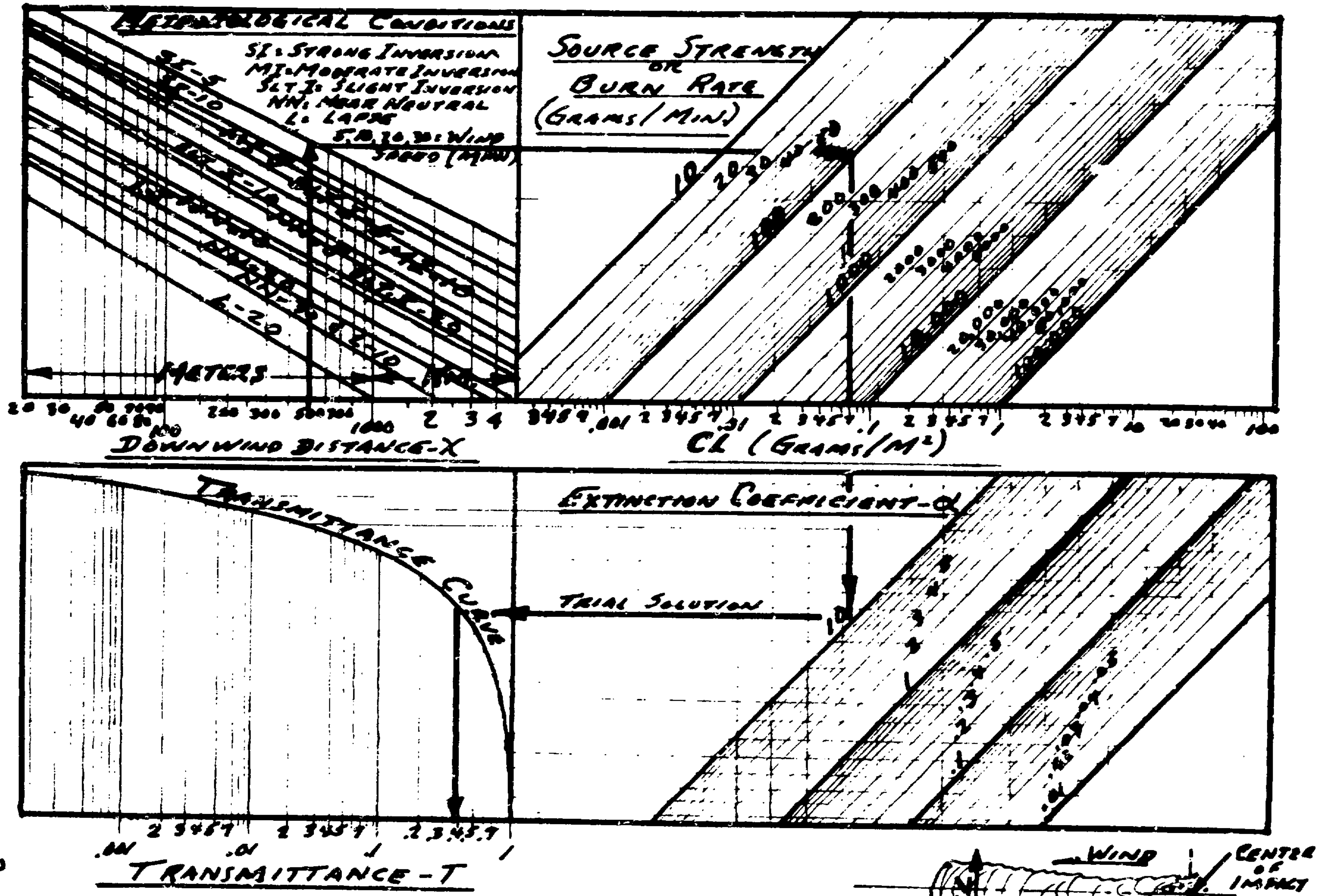


Figure 1- Smoke Transmittance Nomograph

An extinction coefficient, α , is determined for the various smoke agents (for each band of the electro-magnetic spectrum) by laboratory and field testing. So this coefficient is an empirical input to the overall model. Higher values of α indicate better obscuring smoke.

The CL input to the Beer's Law model is calculated from another model - - - the cloud diffusion model. The cloud diffusion model referred to in this report is known as the ORG 17 or Calder-Milly model, which was originally used by the chemical and biological weapons developers.

B. Development of the Nomograph

This nomograph (Figure 1) was developed by calculating CL with the Calder-Milly model and then inputting the CL to the Beer's Law model.

Discussion of CL calculations is in order prior to proceeding with usage instructions. As stated earlier, CL is the integral of smoke concentration across the width of the cloud. This implies a mathematical operation as illustrated below in Figure 2.

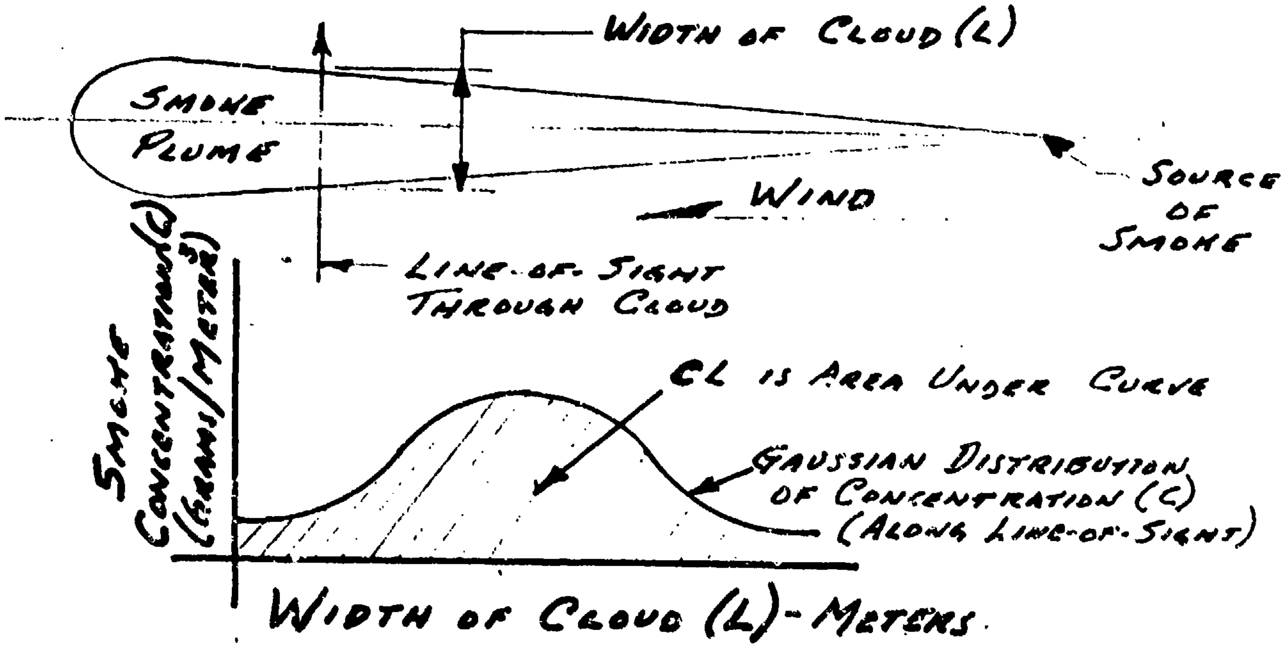


FIGURE 2. CONCENTRATION-LENGTH (CL) CONCEPT

Intuitively one can see that the greater the concentration and length, the greater the CL, and, consequently, the better the obscuration by the cloud. Any attempt to "look" through the smoke plume along the "line of sight" would be counter-measured to a degree that depended upon magnitude of the CL value.

Acquiring CL from a model would, at first thought, indicate the need for a cloud diffusion model that would calculate "smoke concentration" at all points across the cloud and then integrate this concentration across the cloud width. This operation, however, is difficult and requires an accurate value for the parameter (sigma X) which describes the Gaussian concentration-length curve.

Some earlier users of the Calder-Milly model avoided use of the concentration-calculating model. Instead, they resorted to the use of an expedient which yielded easier acquisition of CL values. The gist of this expedient is based (in the jargon of those modelers) on this statement:

> Total dosage from an infinite-length cross-wind line-source aerosol cloud i numerically equivalent to the concentration-length integral of a continuous point source cloud.

That technique was used to obtain the CL portion of the nomograph. The CL curves for various meteorological conditions ... extracted from two published reports[1,2] available from Defense Doc... entation Center. Understanding of this simplifying technique is not ...cessary for usage of the nomograph. It is mentioned here only to show ...w CL values were easily obtained to develop the nomograph. This s... le approach for calculating CL might also be of value for the computer-programmed models.

The nomograph is shown in Figure 1. At the top, the two graphical portions solve for CL as a function of downwind distance, atmospheric stability and wind, and smoke generator source strength. Standard nomographing techniques are then used to obtain the product of CL and the extinction coefficient, α, and to complete the graphical solution of Beer's Law. Final output of the nomograph is transmittance, as a decimal which represents percentage of electro-magnetic energy transmitted.

[1]Palmer, Victor S. and Alexander R. C... ow, A Computational Aid for Line Source Calculations, Technical M...orandum 3-17 (AD 282819), Fort Detrick, MD, July 1962.

[2]Boward, Eugene B, Casualty Estimating for Continuous Point-Source Bio-Aerosol Generator, Technical Memorandum 171 (AD 504775), Fort Detrick, MD.

C. Assumptions and Restrictions

Assumptions upon which this nomograph is based are as follows:

- The smoke cloud is a downwind plume that originated at a point at ground-level.
- All smoke particles remain airborne throughout the downwind distances in the nomograph. There is no fallout of particles.
- Terrain is flat with no vegetation.
- Wind velocity is constant throughout the time period of interest and through the vertical thickness of the cloud.
- Smoke concentration, crosswind and vertical, is Gaussian. Cloud growth is by the diffusion process. There is no cloud "pluming" caused by internal heat in the cloud.

The primary usage restriction is that the nomograph is to be used only for "looking" cross-wind through the cloud.

NOTE: OTHER CURRENT MODELS HAVE SIMILAR ASSUMPTIONS AND RESTRICTIONS. THESE ARE PRIMARILY FOR PURPOSES OF SIMPLIFICATION OF MODELLING EFFORT.

D. Nomograph Usage

Normal usage of the nomograph (Figure 1) is to start in the upper, left hand graph at the downwind distance of interest. Then move up to the meteorological condition; then right to the smoke generator source strength; (burn rate) then down to the pertinent value for extinction coefficient (α); then left to the transmittance curve and down to the calculated value for transmittance. A trial solution of the nomograph (shown in dark arrowed lines starting at downwind distance of 500 meters) shows the procedure for finding transmittance resulting from the following assumed conditions:

- Downwind distance =500 meters. This is the distance from source of smoke cloud downwind to the point where the cloud is being "looked through."
- Meteorological conditions - Stong inversion with 5MPH wind.
- Source strength - 100 grams/minute. This is the "burn rate" of the smoke generator modified by burn efficiency and yield factor, which will be explained later.

Extinction coefficient (α) - 10 meter^2/gram . This is a value for a particular smoke agent and a specific band of the electro-magnetic spectrum. The value is determined from laboratory or field tests.

As shown by the dark arrow trial solution, a transmittance of .4 is indicated for the conditions of this hypothetical case.

IV. RESULTS

A. Usage Examples

The Beer's Law nomograph that resulted from previously described effort is normally used as described in the previous section, "Nomograph Usage"--that is, where the downwind distance, meteorological conditions, source strength (burn rate), and extinction coefficient (α) are known, and it is desired to estimate transmittance through the cloud. However, the nomograph can be run in the reverse direction also. Or it can be used by starting at both ends (transmittance and downwind distance) and running toward the middle to solve for any of the other variables. Examples of these usages will follow.

B. Example 1

L8A1 Smoke Grenade Analysis

1. Background

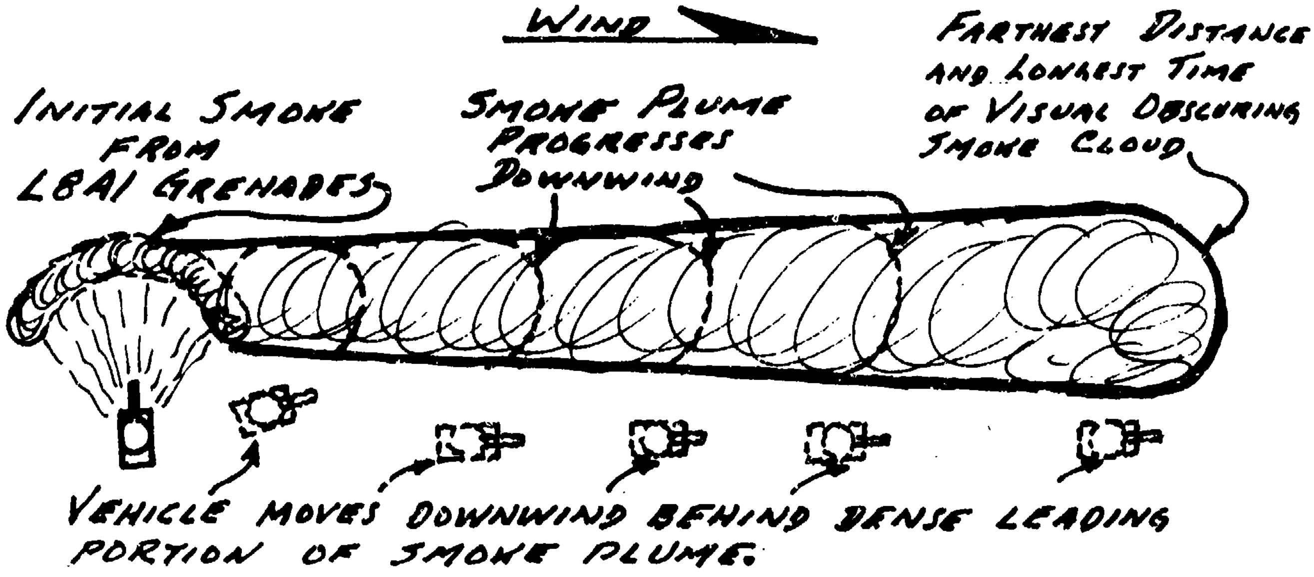
Smoke grenade launchers are usually mounted on tracked vehicles to provide an obscuring cloud upon the desire of the vehicle commander. L8A1 smoke grenades are fired from two launchers, either 4-tube or 6-tube to generate an immediate screen adjacent to the vehicle. The smoke generating agent (Red Phosphorus) continues to burn and yields a downwind plume, behind which the vehicle can remain obscured from enemy vision. An important characteristic of the grenade is its "burn rate vs. time" - - - the weight of red phosphorus (RP) burned per unit time (grams/minute). Grenades with different "total burn times" would have different burn-rates.

In this example, two combat scenarios are assumed:

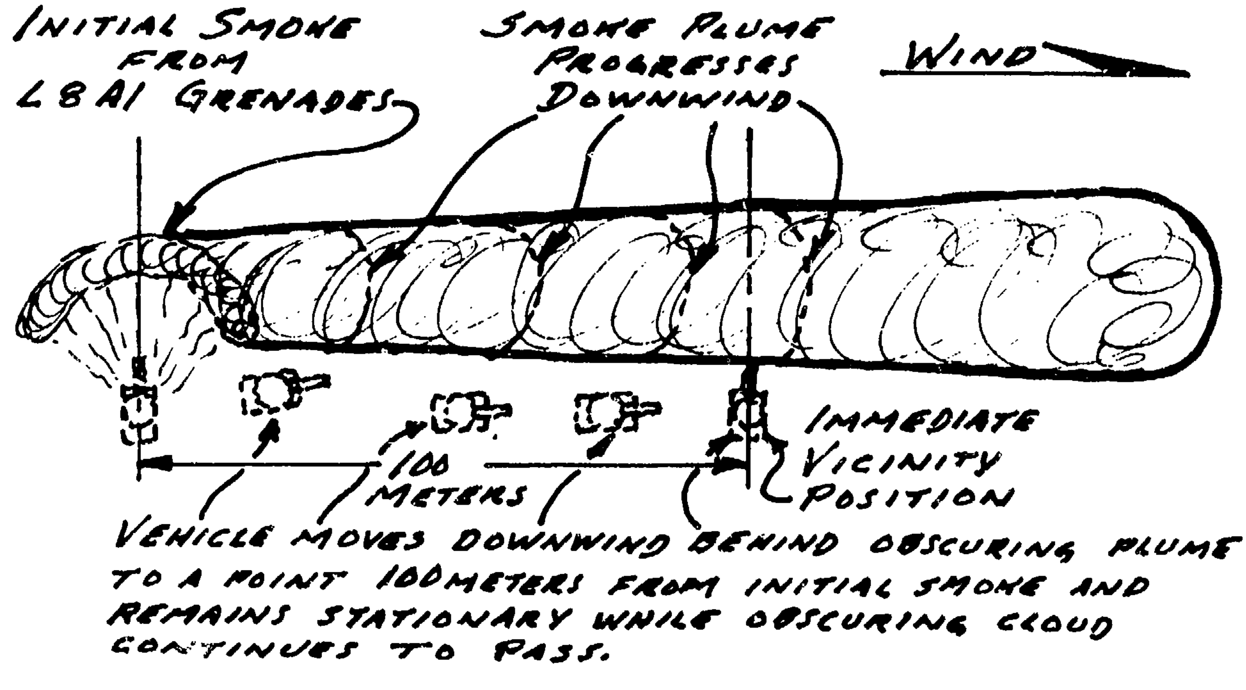
Scenario 1. The vehicle commander wishes to fire his smoke grenades and then move the farthest distance downwind behind the obscuring smoke plume.

Scenario 2. The vehicle commander wishes to fire his smoke grenades and then remain, obscured, in the immediate vicinity for the longest time.

Figure 3 illustrates the two scenarios.



SCENARIO 1 — SHOOT & RUN



SCENARIO 2 — SHOOT & STAY

FIGURE 3 — SMOKE GRENADE SCENARIOS

2. Objective: To determine effect of L8A1 Grenade burn time upon time/distance duration of visually obscuring cloud.

3. Approach: Assume hypothetical L8A1 grenades with different total burn times (and, consequently, different burn-rates) and a linear burn-rate decay. With assumed meteorological conditions and extinction coefficient, determine from the nomograph:

a. For scenario 1, how far downwind an obscuring cloud would extend.

b. For scenario 2 how long an obscuring cloud would exist in the immediate vicinity.

4. Assumptions: 8 L8A1 Grenades with 360 grams Red Phosphorus (RP) each. Point source smoke at centroid of impact pattern. Burn-rate/time for 1, 2, 3, 4 & 5 min. total burn time. Extinction coefficient, α = 2.6 for visual/RP.

Total yield factor = Burn efficiency X yield factor

= (.66) (4 1/2) = 3

Because of the hygroscopic nature of phosphorus smoke, the mass of smoke increases as a function of relative humidity. The yield factor is used to correct burn-rate to accommodate this phenomenon. The factor varies with relative humidity.

Meteorological Conditions - Near neutral @ 10mph wind.

- Pasquill D

Downwind distance - (Scenario 1) - Variable

- (Scenario 2) - 100 meters

Visual Obscurance - At Transmittance $\leq$ .10

5. Scenario 1 (Shoot and Run) Nomograph Solution:

A graph (Figure 4) was constructed to show assumed "burn rate" curves for each of the "total burn times." This is required for both scenarios. Then the initial "burn rate" (q) was determined, from the graph, for each of the five "total burn times" (1, 2, 3, 4 & 5 minutes). These were 720, 360, 242, 180, and 142 grams/minute, respectively. Then the "total burn-rate" (Q) for 8 L8A1 grenades was calculated as follows:

Q = (q for 1 grenade) (8 grenades) (total yield factor 3)

Q = (720) (8) (3) = 17,300 grams/minute
= (360) (8) (3) = 8,650 grams/minute
= (242) (8) (3) = 5,800 grams/minute
= (180) (8) (3) = 4,320 grams/minute
= (142) (8) (3) = 3,410 grams/minute

These "total burn rates" are the highest burn rates from each hypothetical grenade and would yield the most dense smoke to emanate from each. Therefore, this initial smoke will remain an obscuring smoke longer than any smoke generated later. Calculating the downwind distance at which this initial smoke would yield no greater than .1 transmittance would indicate how far downwind an obscuring smoke would extend. This would be the solution for Scenario 1 (Shoot and Run)

The downwind distance calculations for all five hypothetical grenades were solved on the nomograph as illustrated in Figure 5. The nomograph was entered at transmittance of .1, solution proceeded up to transmittance curve, right to α of 2.6, up to each of the five "total burn rates," then left to the "near neutral -10" meteorological condition, and down to the five indicated downwind distance solutions. Results are shown on Figure 6.

6. Scenario 2 (Shoot and Stay) Nomograph Solution:

To solve for this scenario, it was necessary to calculate how long an obscuring cloud would exist in the immediate vicinity of the point where the L8A1 grenades were fired. "Immediate vicinity" was arbitrarily defined as a point 100 meters downwind of the initial smoke source.

For solution, it was necessary to construct "Transmittance vs. Time" curves for each of the five hypothetical grenades. To accomplish this, the "total burn rates" (over the entire burn times) were required. The "burn-rates" for each grenade were extracted from Figure 4 at 10 or 20 second intervals. The "total burn rates" for 8 grenades

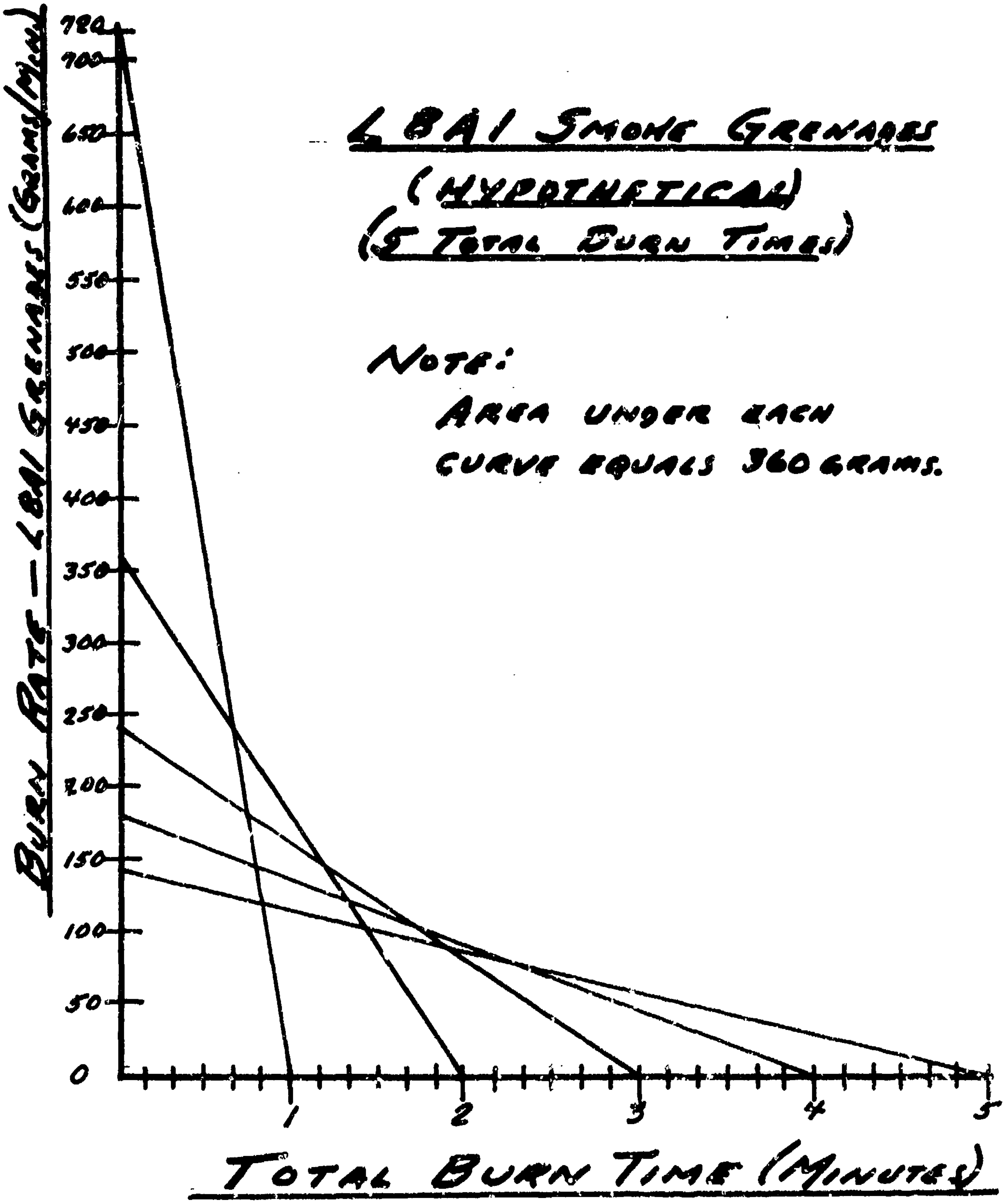


FIGURE 4-BURN RATE CURVES-L8A1 GRENADES

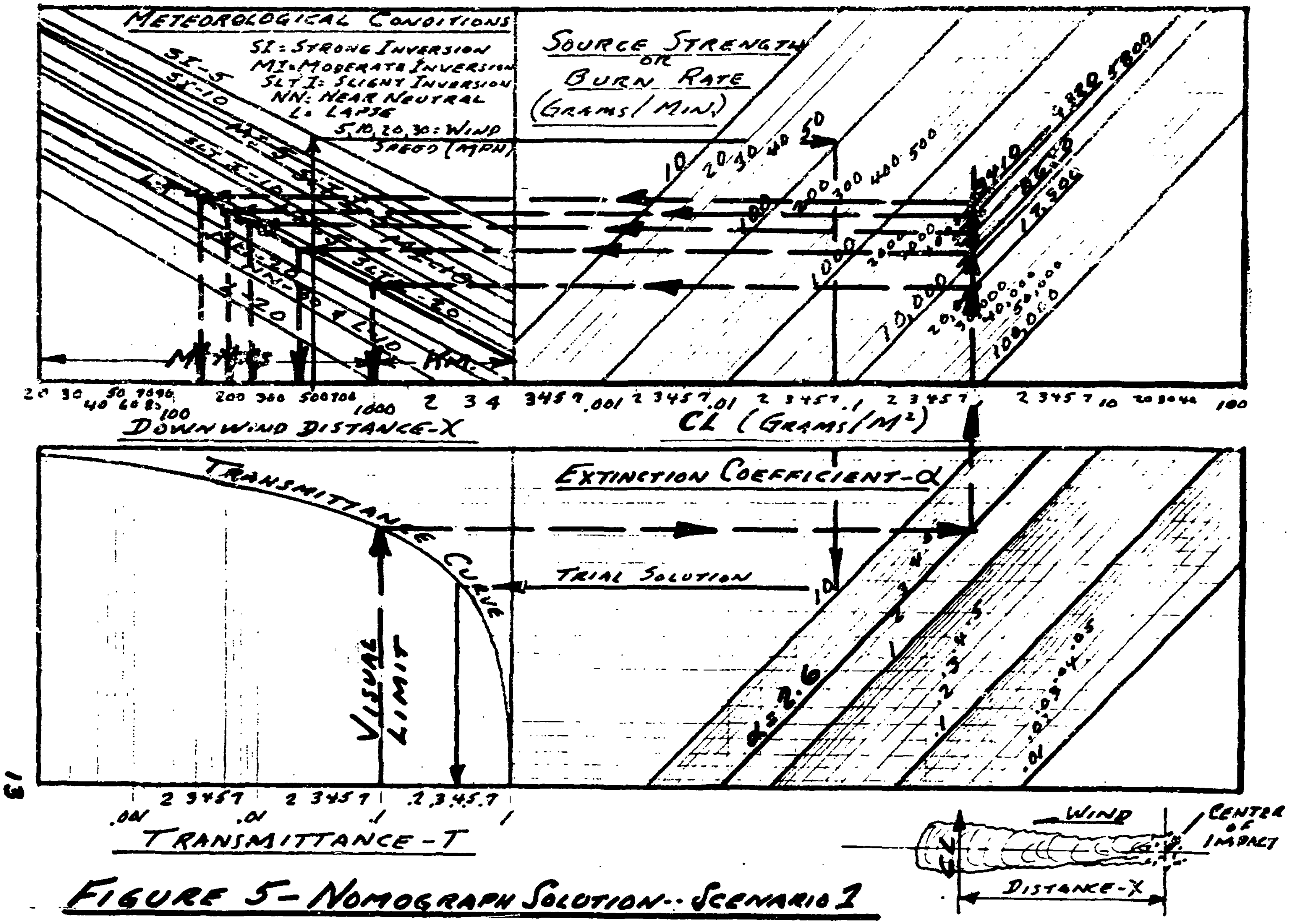


FIGURE 5- NOMOGRAPH SOLUTION-- SCENARIO I

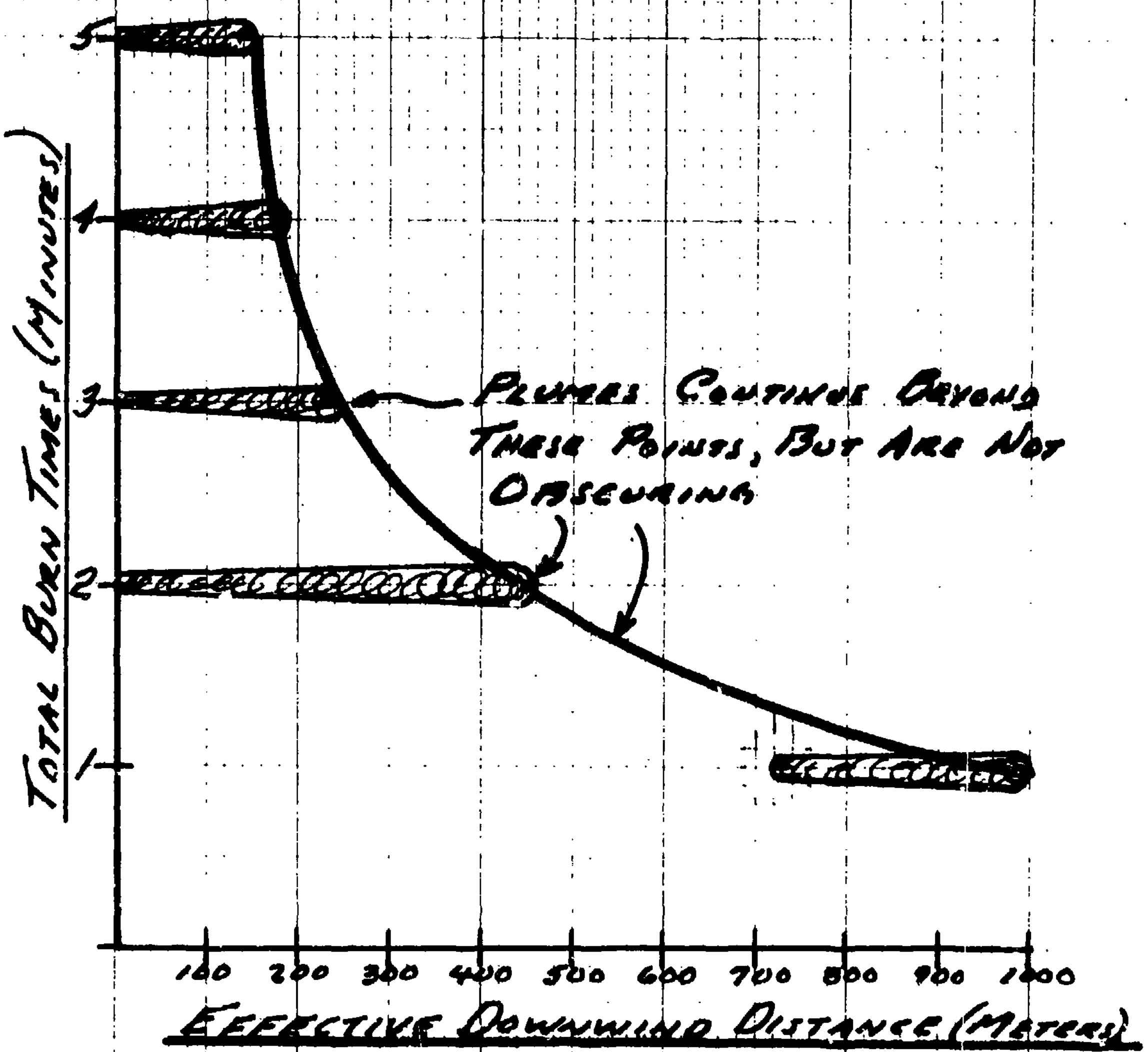


FIGURE 6 - SCENARIO I RESULTS

were calculated as was done for Scenario 1. By entering the nomograph at a downwind distance of 100 meters and proceeding through "near neutral -10", over to each "total burn rate" and on through to the Transmittance Scale, the transmittance at each 10 or 20 second time-period was determined. Sample solutions are shown on Figure 7. Transmittance vs Time curves were plotted from the resulting nomograph calculations. Figure 8 shows results.

Figure 8 shows transmittance of .1 as the maximum value for visual obscurance. Obscuration time for each of the five grenades was taken from this graph at points where the curves crossed the .1 transmittance level. Results are tabulated below.

TABLE 1

OBSCURATION TIME

GRENADE BURN TIME (MIN)	OBSCURATION TIME (SEC)
1	~ 72
2	~ 102
3	~ 122
4	~ 122
5	~ 90

NOTE: Obscuration times above were as corrected for the time required for smoke to travel from initial point to the 100 meter downwind distance. Nomograph Figure 9 yields correction values.

The above results are shown in Figure 10, superimposed on the results from Scenario 1.

7. Discussion (Scenario 1 and 2)

Figure 10 shows clearly that the short burn time (1 minute) grenade yields, by far, the greatest downwind distance (and longest obscuration time) for Scenario 1 (Shoot and Run). However, for the Scenario 2 (Shoot and Stay), the 1 minute grenade yields the shortest time for an obscuring cloud. The 3 and 4 minute grenades are quite similar. This was also evident in Figure 8 where the 3 and 4 minute grenades crossed the visual obscuration level at almost the same point. For the best compromise solution to Scenarios 1 and 2, the 2-minute grenade would appear to be a good selection.

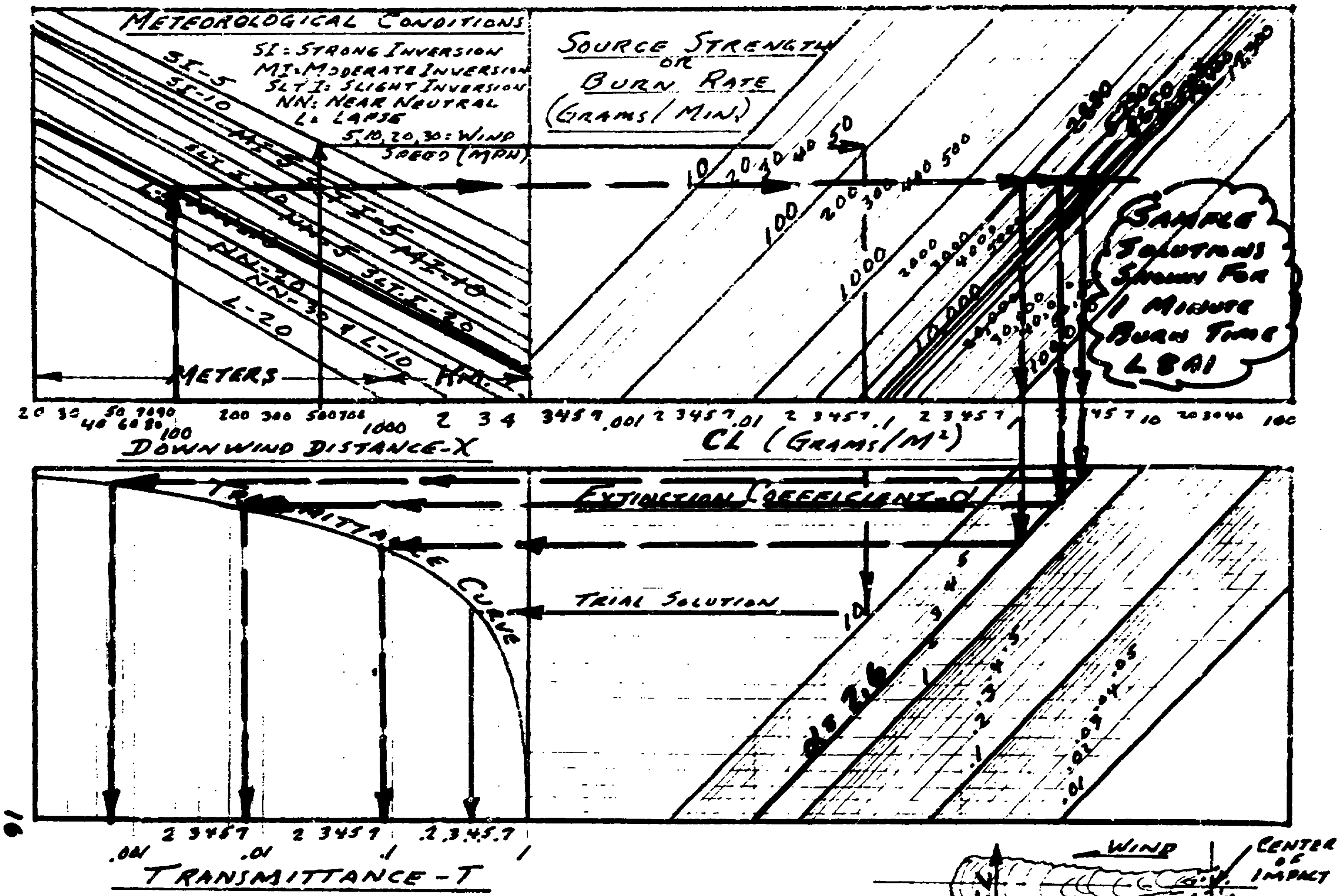


FIGURE 7—NOMOGRAPH SOLUTION—SCENARIO 2

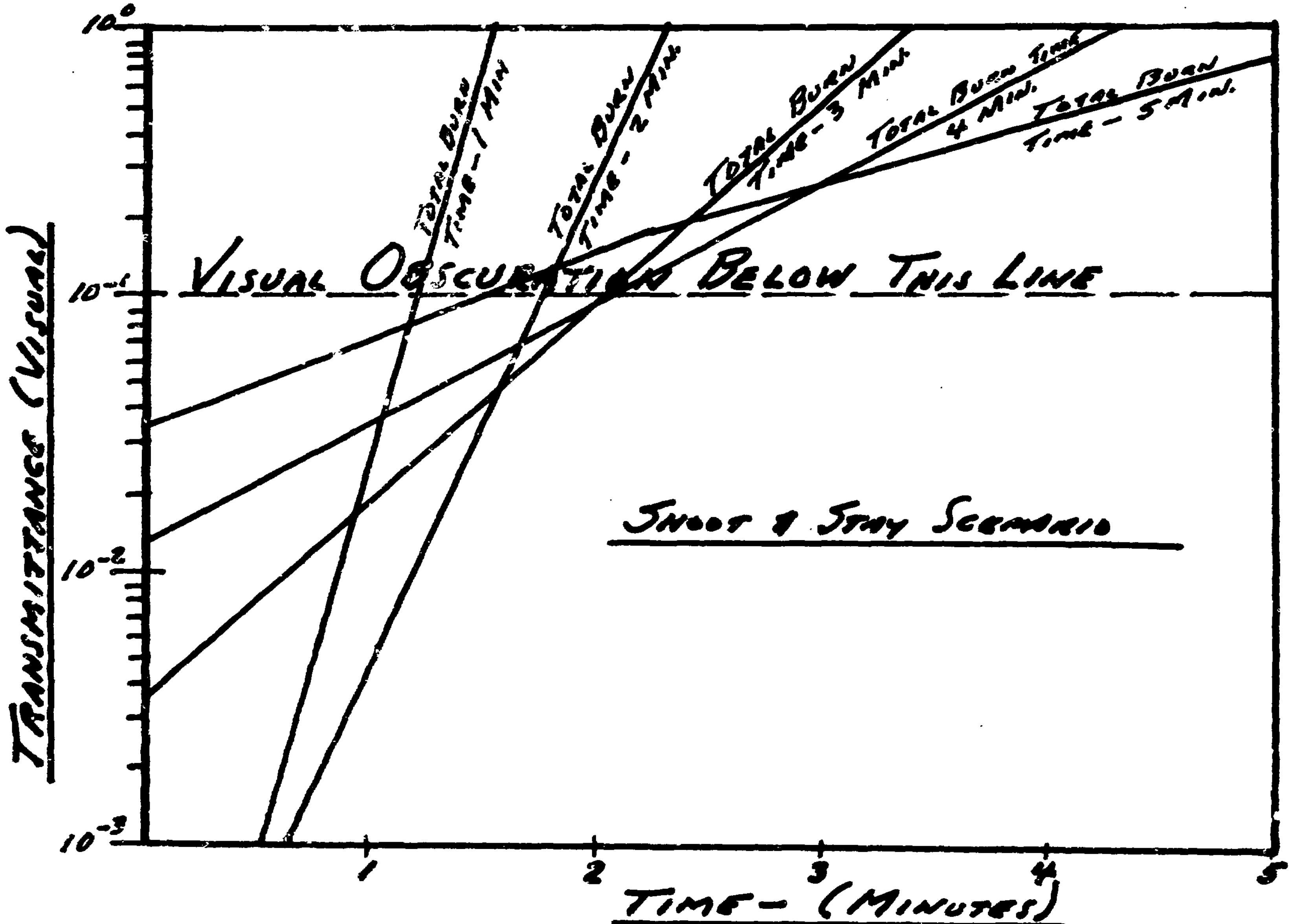


FIGURE 8 - TRANSMITTANCE - TIME CURVES — SCENARIO 2

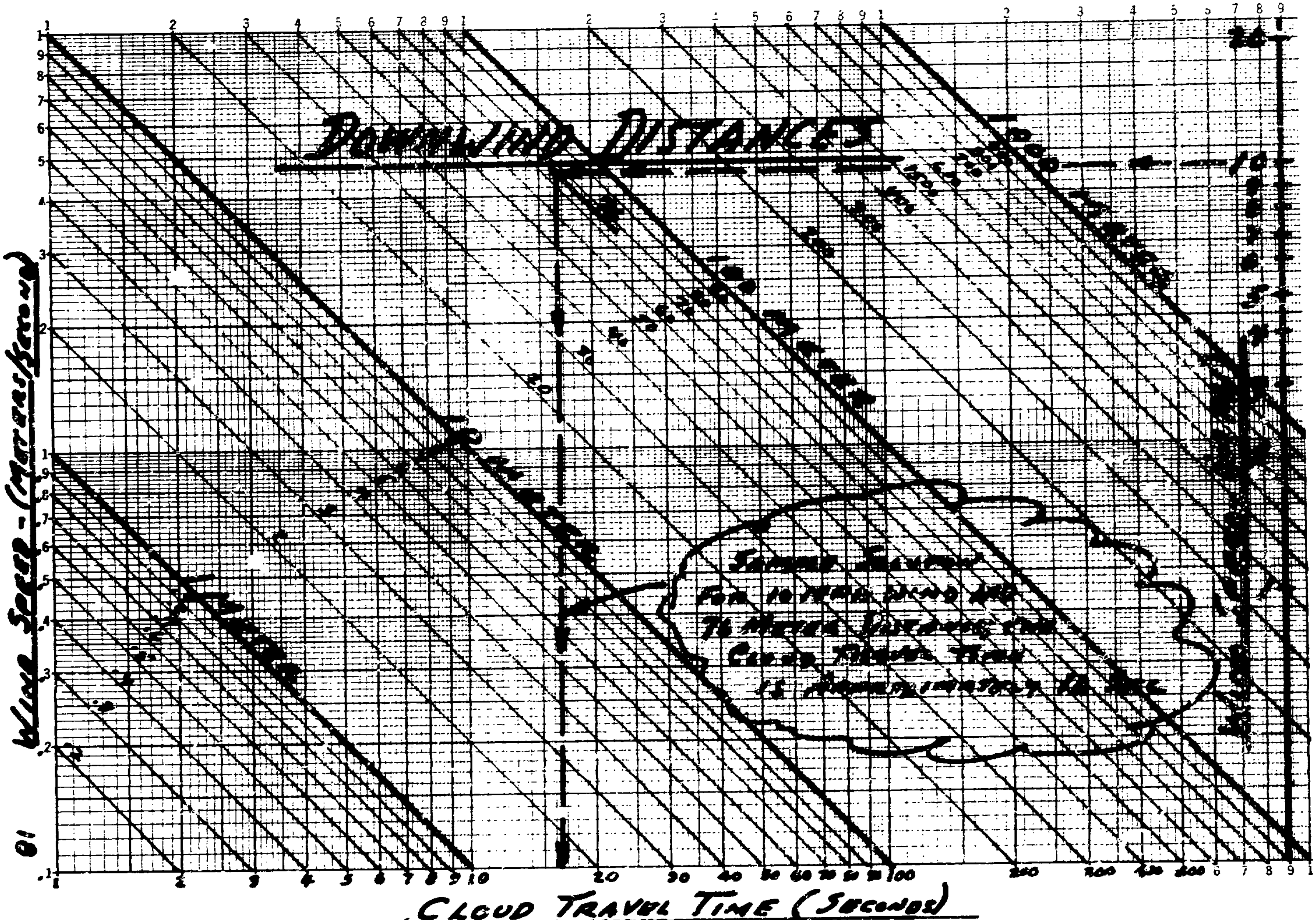


FIGURE 9 - CLOUD TRAVEL TIME NOMOGRAPH

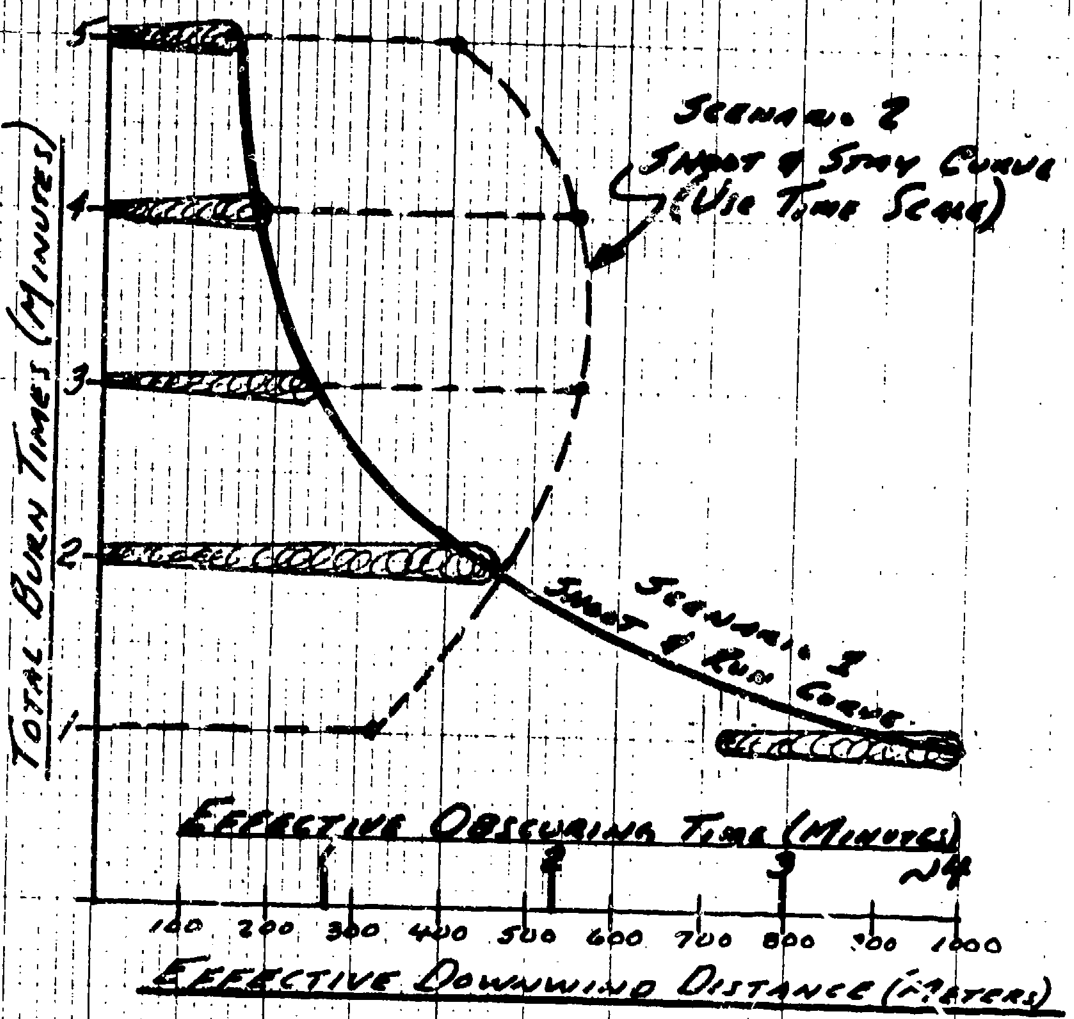


Figure 10 – Scenario 1 & 2 Results

It should be noted that the validity of such an analysis is dependent upon accuracy of the cloud diffusion model and other assumptions - - - particularly the "burn-rate" curves assumed for the grenades.

C. Example 2

L8A1 Smoke Grenade Transmittance Predictions

1. Background

Test trials, with L8A1 Grenades, have been conducted at Dugway Proving Ground. Test conditions were recorded and transmittance data were taken. Then the "Transmittance vs Time After Function" was plotted. This type of information is useful for indicating the degree of obscuration provided by the grenades. Generation of such information from use of a model would, at times, be of value. The nomograph can provide the information as in this example.

2. Objective: To plot "Transmittance vs. Time" curves from nomograph solutions and to compare them with results from actual field tests.

3. Approach: Use nomograph to calculate transmittance/time throughout the burn time of the L8A1 grenades. Plot results on same graph with results from field tests. Compare the two plots.

4. Assumptions:

- 6 L8A1 Smoke Grenades each with 360 grams of red phosphorus (RP)
- Line of sight 76 meters downwind of source of smoke. This is the downwind distance on the nomograph.
- Meteorological conditions - Near Neutral with 10 mph wind (Pasquill D).
- Total burn time of 3 minutes.
- Burn-rate per Figure 4, for 3 minutes burn time. (Linear burn-rate decay)
- Total yield factor of 3.
- Extinction coefficient 2.6, for RP used in visual spectrum.

5. <u>Nomograph Solution</u>: Burn-rate for individual grenades were taken from Figure 4 for the 3-minute total burn time. Total burn-rate for the 6 grenades was calculated as for Example 1 (Section IV B5). Transmittance was estimated by use of the nomograph, for each total burn rate. Sample calculations are shown in Figure 11. Results are tabulated in Table 2 (L8A1 Burn Rates).

Table 2

L8A1 Burn Rates

Time (Seconds) Initial	Offset	q Burn Rate for 1 Grenade (Grams/Min)	Q Total Burn Rate for 6 L8A1 Grenades	Transmittance from Nomograph
0	16	240	4320	.007
20	36	213	3840	.02
40	56	186	3350	.03
60	76	160	2900	.05
80	96	133	2400	.07
100	116	107	1940	.10
120	136	80	1430	.20
140	156	53	950	.30
160	176	27	490	.52
180	196	0	--	--

These results were plotted (Figure 12) with the initiation-time offset approximately 16 seconds to allow for time required for smoke to travel downwind 76 meters to line-of-sight. Transmittance values from the nomograph are plotted in dash-lines. The jagged plot is measured transmittance from Trial 2 (DP1003) 31 Oct 1977 test conducted at Dugway Proving Ground.*

*Test plot, basis for Figure 12, was extracted from: Volume I, Smoke Test of the Grenade, RP, L8A1 (Phase 1b), Final Test Report, June 1978. DPG Document No. DPG-FR-77-315.

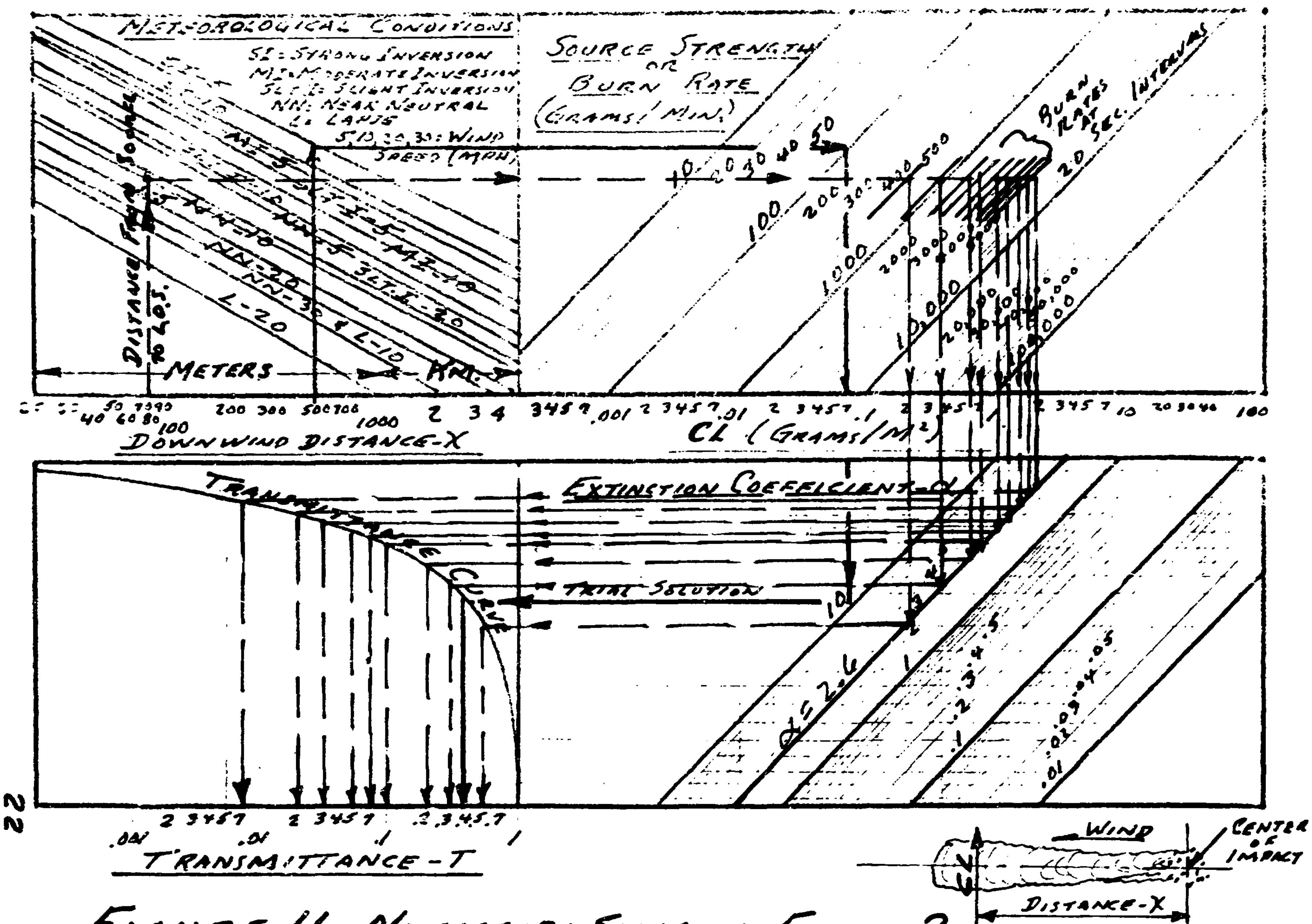


FIGURE 11—NOMOGRAPH SOLUTION-EXAMPLE 2.

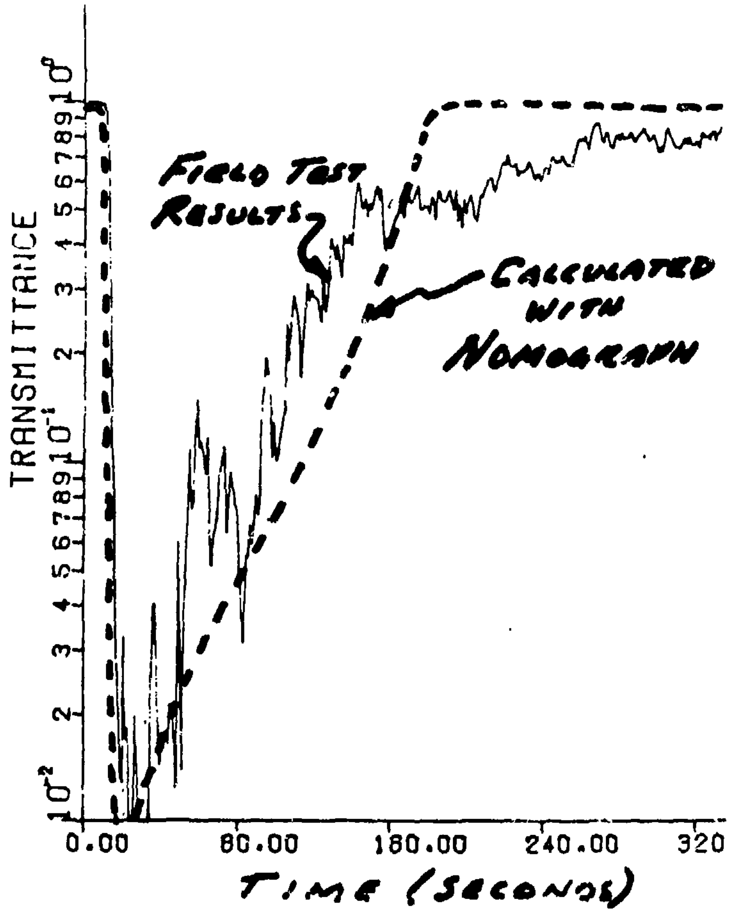


FIGURE 12 — TRANSMITTANCE-TIME CURVES FOR EXAMPLE 2 (L8A1 GRENADES)

6. Discussion: The degree to which nomograph calculated transmittance agreed with the field test data is evident in Figure 12. The jagged curve from field-test data is typical of transmittance-time measurements. Fluctuations may be due to wind gusts. The nomograph solution is a more-smooth curve because wind is assumed constant and the burn-rate/time is non-fluctuating. If wind gustiness with speeds above and below the 10mph wind were assumed, one could calculate transmittance-time curves at 15 and 5 mph. These curves would tend to span the field-test fluctuations.

D. Example 3

Required Source Strength (Burn Rate)

1. Background

Developers of smoke generating systems and designers of smoke attacks could have use for information available from exercise of Beer's Law, which is probably the nearest thing to an engineering equation that the smoke system designer has available. If a desired terminal effect (transmittance) is needed at a specified distance, Beer's Law can be used to determine the required CL for a given extinction coefficient. The nomograph can be used to estimate (for a specific meteorological condition) the required source strength (burn-rate).

2. Objective: To estimate required source strength (burn-rate) for a smoke munition that would yield a desired transmittance at a given downwind distance under an assumed set of conditions.

3. Approach: Use nomograph by starting at each end (transmittance and downwind distance) and working toward the middle to the source strength curves.

4. Assumptions:

- Downwind distance - 200 meters. This is distance from smoke source to line-of-sight where required transmittance is to be demonstrated.
- Meteorological Conditions - Near Neutral, 10 mph wind
- Pasquill D
- Extinction coefficient - .22
- Total yield factor - 3
(See IV B 4 for details)
- Desired transmittance $\leq$ .01

5. Nomograph Solution: See Figure 13. Enter the nomograph at downwind distance of 200 meters, proceed up to "near-neutral-10" meteorological curve, and then right through all the source strength curves. Now enter the nomograph at transmittance of .01, proceed up to transmittance curve, right to α value of .22 and then up through all source strength curves. At the intersection of the horizontal and vertical constructed lines is the indicated required source strength, or burn-rate ($\geq$ 80,000 grams/minute). This is the burn-rate required after the yield factor has been taken into account. Actual required burn-rate of the smoke generator would be equal to or in excess of:

$$\frac{80{,}000 \text{ grams/min}}{3 \text{ Yield Factor}} = \text{Approx. } 27{,}000 \text{ grams/min.}$$

Note from the CL scale on the nomograph that required CL is approximately 15 grams/meter.^{2}

6. Discussion: This same technique (working the nomograph from both ends toward the middle) could also be used for:

a. Determining required extinction coefficient when all other system parameters and requirements are known.

b. Determining the worst meteorological conditions under which desired transmittance would be demonstrated by a given weapon system.

c. Determining trade-off combinations between source-strength (burn-rate) and extinction coefficient (α) that would yield same transmittance - - - with all other parameters and requirements remaining constant.

Such manipulation of the nomograph should be useful to the smoke generator developer who is interested in optimizing his generator design.

E. Example 4

Sensitivity Analyses

1. Background

During development and evaluation of smoke generating and electro-optical (EO) hardware, it may at times be desirable to know how sensitive the "smoke vs. EO" systems are to variations in system parameters. The nomograph is inherently well-adapted to provision of such information.

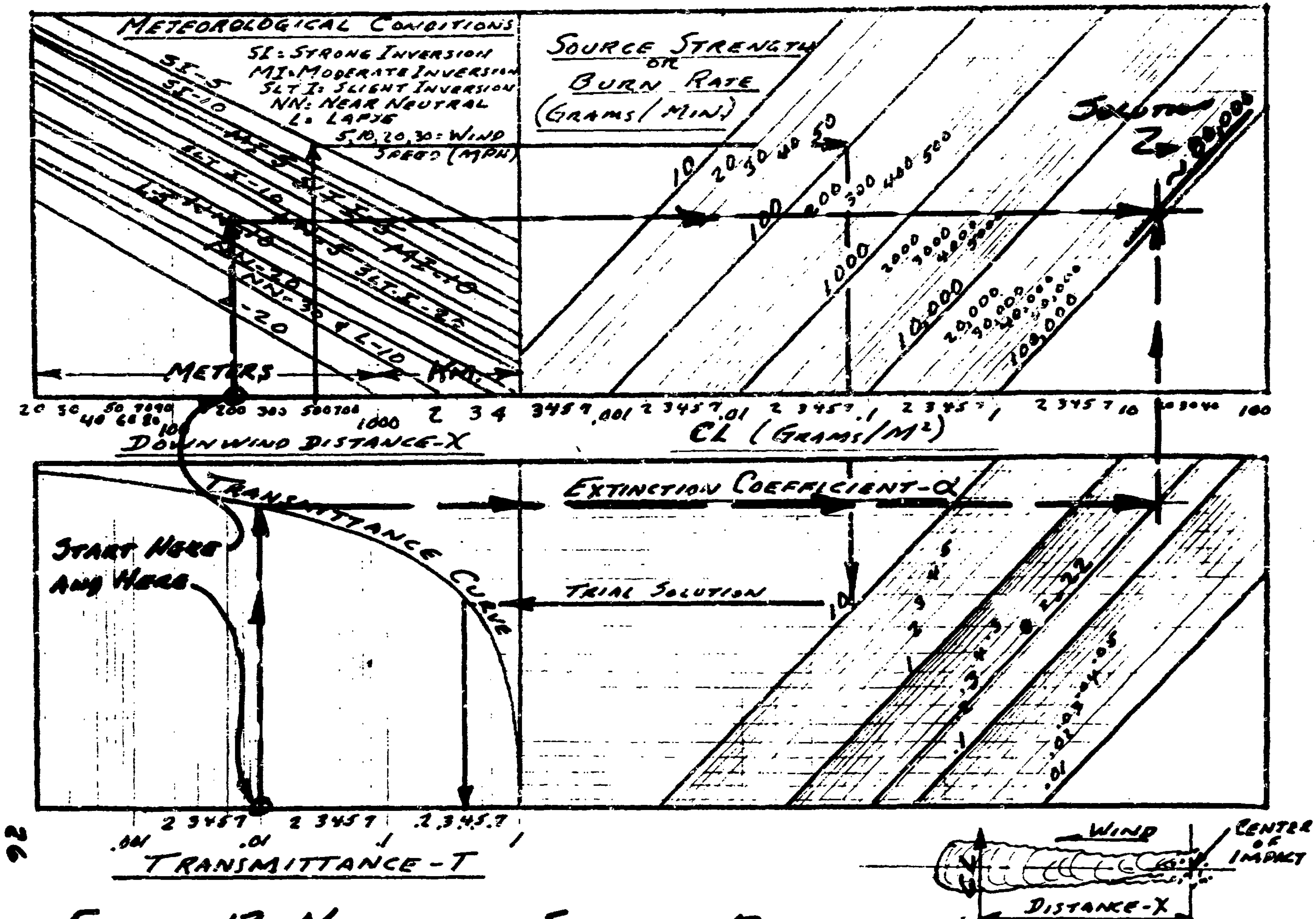


FIGURE 13-NOMOGRAPH SOLUTION-EXAMPLE 3

2. Objective: To illustrate how the nomograph may be used for simple sensitivity analyses relating to parameters of "smoke vs. EO" systems.

3. Approach: Show sample sensitivity analyses on nomograph.

4. Assumptions:

It is desired to determine:

a. How transmittance would change if meteorological conditions changed from near neutral-5 mph wind to near neutral -10 mph - - - all other things remaining the same.

b. How transmittance would change for a given change in extinction coefficient, .

c. How required source-strength/burn rate) would change for a given change in required transmittance.

5. Nomograph Solutions:

a. Figure 14 illustrates the technique for determining how the change of meteorological conditions from near neutral -10 mph to near-neutral -5 would affect transmittance. The nomograph is constructed so that the magnitude of vertical change in any parameter carries all the way through. For instance, in Figure 14, at an arbitrarily assumed downwind distance of 100 meters, the vertical distance between the near neutral -10 and near neutral -5 conditions is shown transplanted directly to the transmittance curve. The illustrated result is that the meteorological change causes transmittance change as shown.

A glance at the meteorological condition curves, and their vertical separations, indicates the effect of these conditions upon "smoke vs. EO" system performances.

b. Figure 15 shows how a change in extinction coefficient, α, from 3 to 1 would affect transmittance estimates. The vertical distance between the 3 and 1 curves is directly transplanted to the transmittance curve. As shown, the effect depends, in part, upon the portion of the transmittance curve to which the α change is applied.

The same technique can be used to determine effect of changes in source strength (burn rate). Here, again, the vertical distances between compared curves need be transplanted to the transmittance curve.

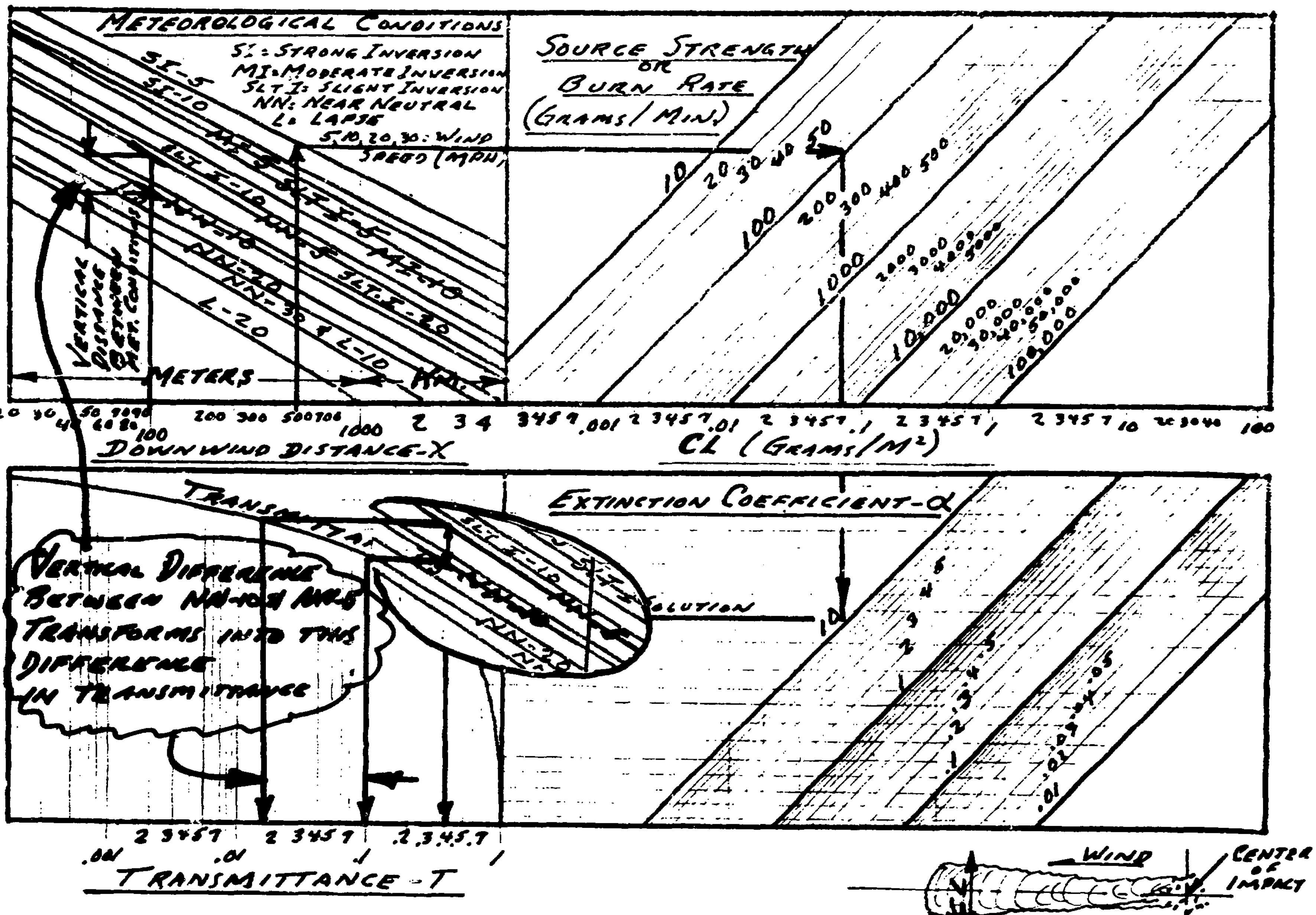


FIGURE 14—SENSITIVITY TO METEOROLOGICAL CHANGES

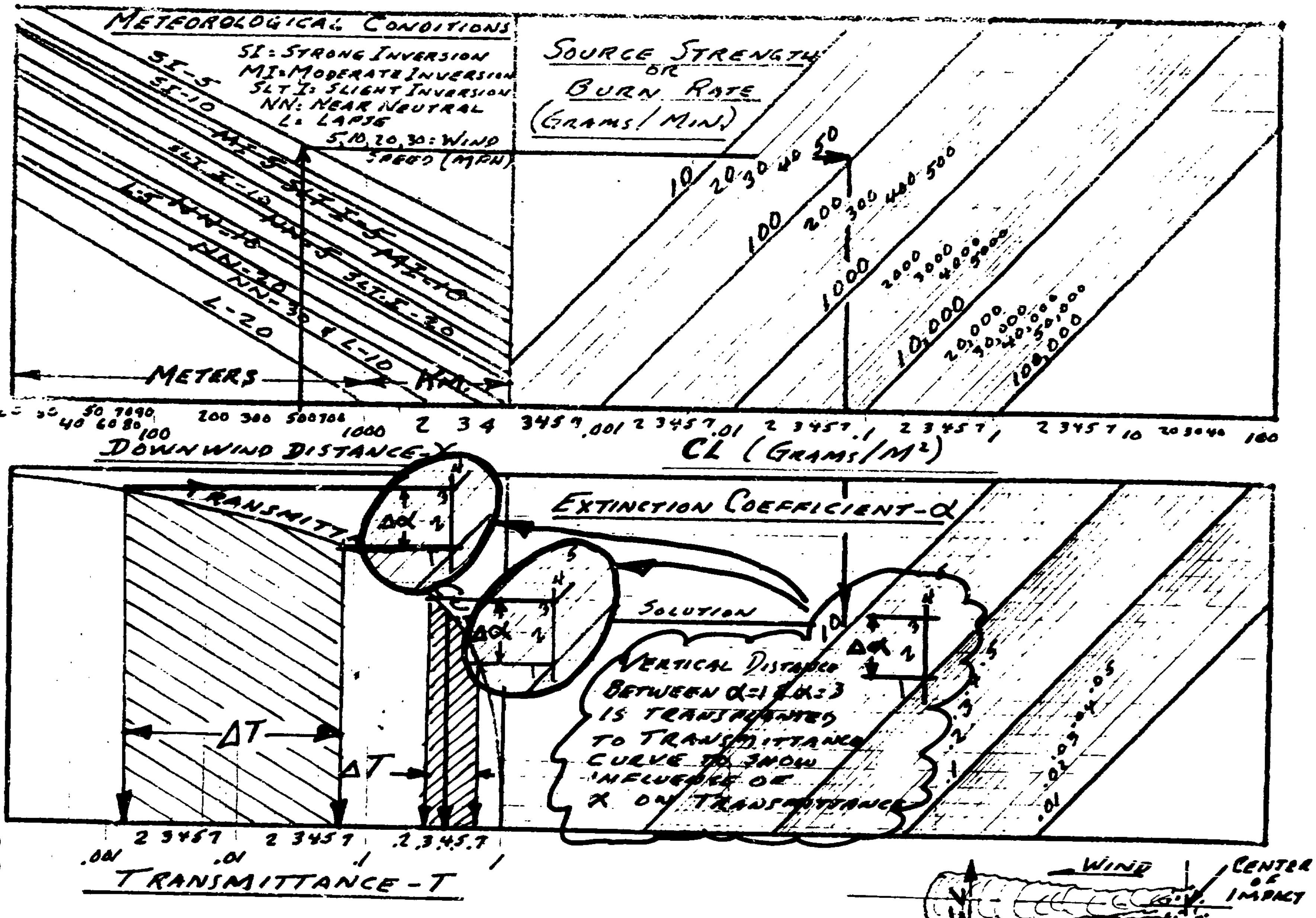


FIGURE 15—SENSITIVITY TO CHANGES IN α

c. Figure 16 illustrates how source strength requirements would change for a given desired change in transmittance. Here the vertical change on the transmittance curve is transplanted to the source strength (burn rate) curves. Decreasing allowable transmittance from .1 to .01 requires a change in source strength, for instance, from 2600 to 4600 grams/minute. Note that to decrease the transmittance the source strength must be increased.

F. Example 5

Casualty Estimates

1. Background: It is possible that smoke clouds (ours or the enemy's) could be toxic and could generate casualties among personnel who inhaled the aerosol. Estimates of casualty levels could be desired at times. The nomograph can be used to obtain such estimates.

2. Objectives: To illustrate how the nomograph may be used to obtain estimates of smoke dose that exposed personnel might acquire, and to show how casualty estimates are obtained.

3. Approach: Show sample use of nomograph, calculations, and use of log normal graph paper to estimate casualties from smoke clouds.

4. Assumptions:

- Smoke attack as follows:

  Meteorological Conditions - Near Neutral - 10mph wind
  Burn rate (total) - 20,000 grams/min.

- Personnel action as follows:

  Walk crosswind through cloud 100 meters downwind from source.
  Walk at 150 meters/min velocity
  Breathe at 20 liters/minute (2×10^{-2} m^3/min)

- Smoke Agent Characterisicts:

  Id_{50} of 4×10^{-3} grams. This Id_{50} is the amount of smoke which, inhaled by a number of people, would result in 50% of those people becoming casualties.

  Dose-response relationship of Probit 2. This curve allows estimates of casualties for other than an Id_{50}.

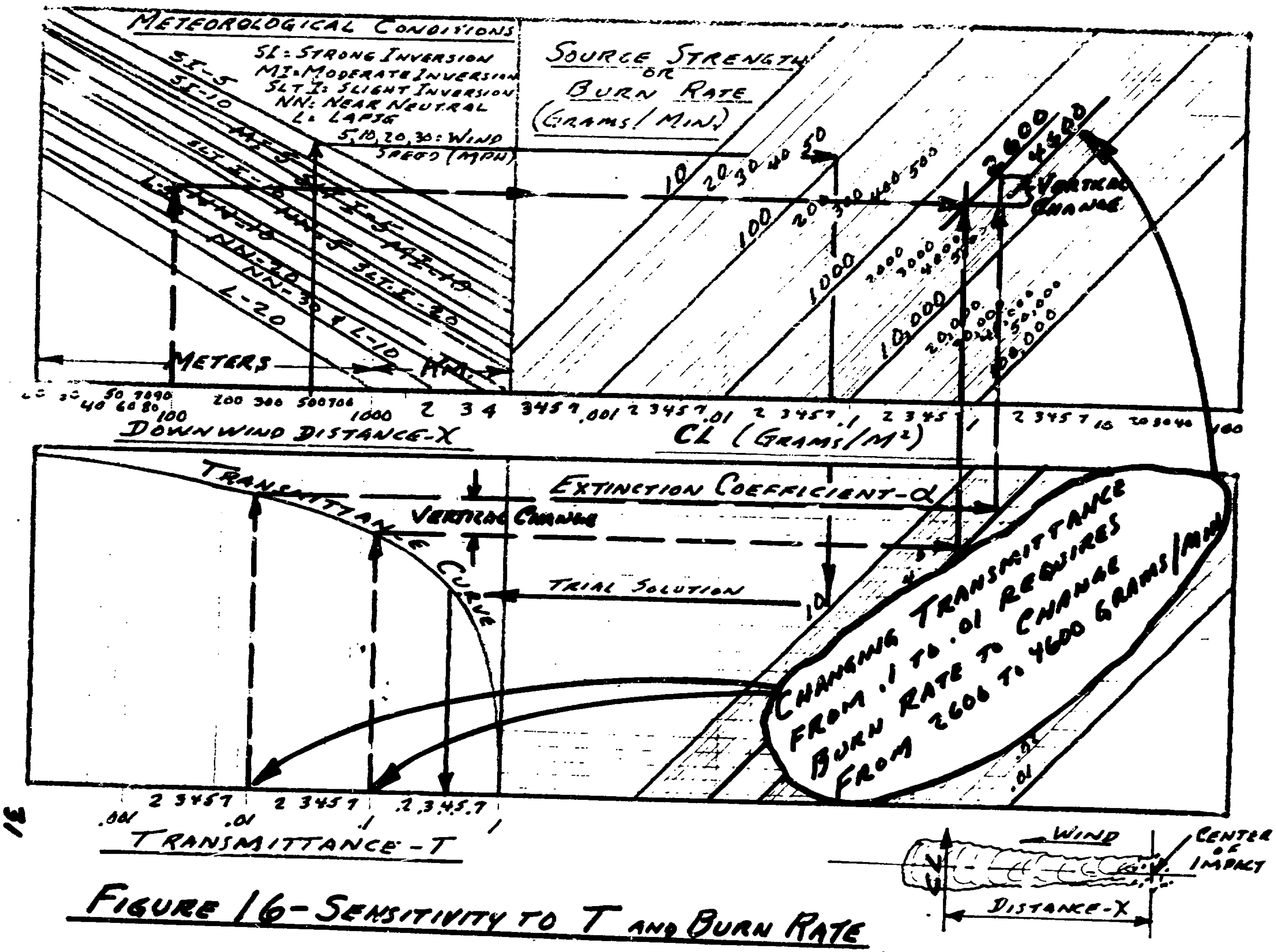


FIGURE 16-SENSITIVITY TO T AND BURN RATE

5. Solution:

First the nomograph is used per Figure 17 to estimate the CL at a point 100 meters downwind of the smoke source, during meteorological conditions of near neutral with 10 mph winds. As shown, the estimated CL for the assumed attack is approximately 5.3 $grams/meter^2$.

The smoke dose inhaled by personnel walking at 150 meters/min. all the way through the cloud while breathing at 20 liter/min. is found as follows:

$$\text{dose} = \frac{(\text{CL})\ (\text{Breathing Rate})}{(\text{Velocity Through Cloud})}$$

$$\text{dose} = \frac{\left(5.3\ \frac{\text{grams}}{\text{meter}^2}\right)\left(2 \times 10^{-2}\ \frac{\text{meter}^3}{\text{min}}\right)}{\left(1.5 \times 10^{2}\ \frac{\text{meter}}{\text{min.}}\right)}$$

$$\text{dose} = 7 \times 10^{-4}\ \text{grams}$$

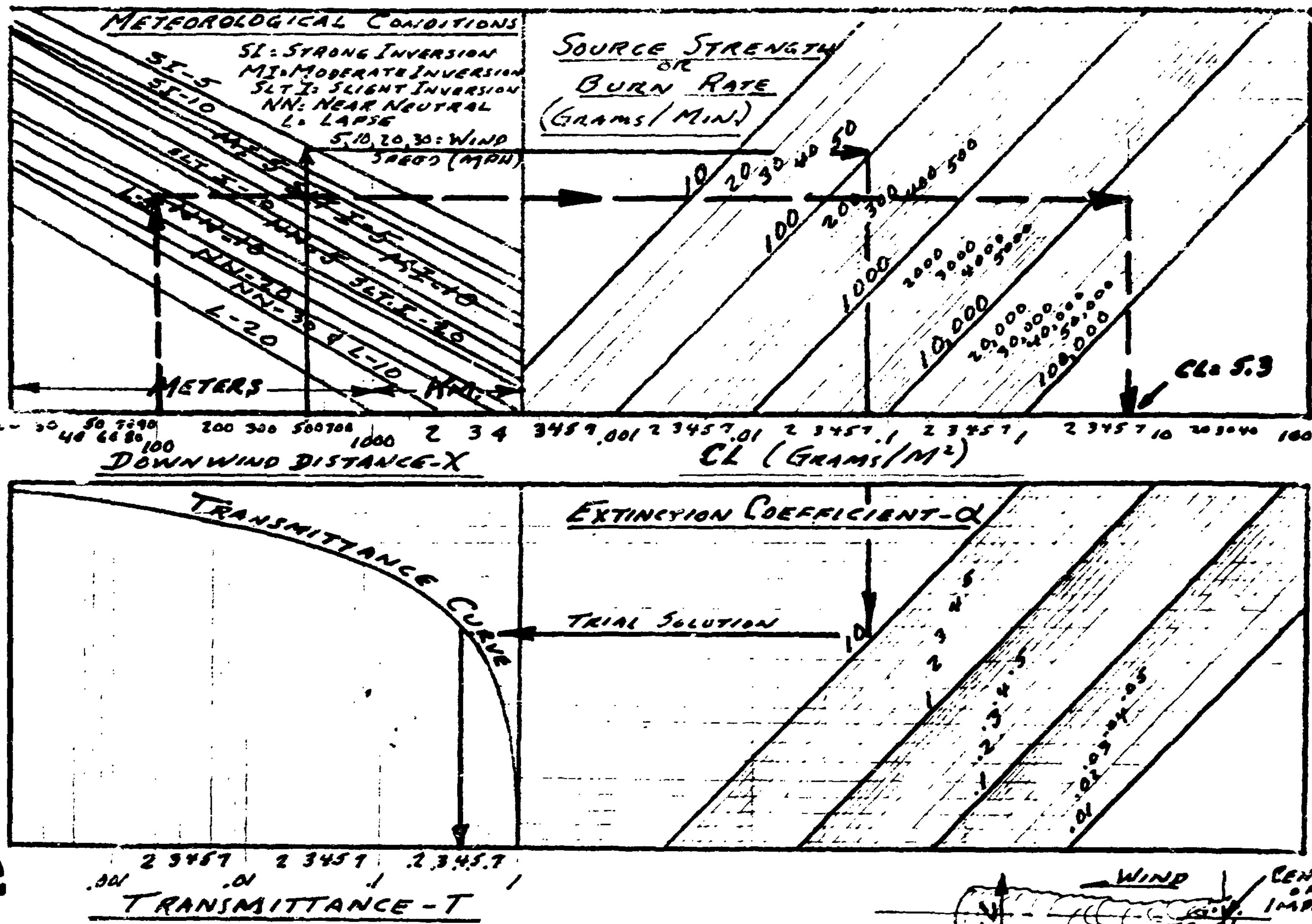
Expected casualties from a dose of 7×10^{-4} grams are found as illustrated on Figure 18, which is plotted on log-normal graph paper. As shown, the horizontal scale is marked so that the Id_{50} (4×10^{-3}) is in the middle log scale. Then a vertical line is drawn from the 4×10^{-3} point on the scale to the 50% casualty line. Then the dose-response curve is drawn through the intersection of the 4×10^{-3} and 50% lines. The slope of the line is Probit 2, which means the slope is 2 Probits per log dose. (Probit scale is on the right hand side of the graph). Now casualties can be read from the graph for doses varying from 10^{-4} to 10^{-1} grams. For the calculated dose in this example (7×10^{-4} grams) the estimated casualties (6%) is found as illustrated on Figure 18.

NOTE: Numbers used in this example are for illustration purposes only. Values for Id_{50} and dose response curve are assumed, not real, numbers. Real numbers should be available from toxicology effort.

G. Other Possible Analyses

1. General

The nomograph may be used for comparison of smoke generator concepts. The model is probably better when used for comparative purposes than for obtaining absolute values of any parameter. That is, the effective ranking of a number of concepts (as analyzed by use of the nomograph)



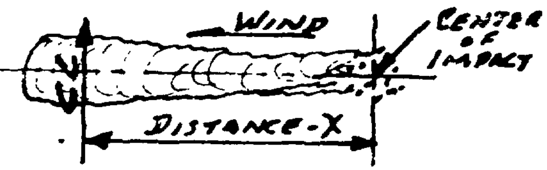


FIGURE 17—NOMOGRAPH SOLUTION FOR CL

Casualty Estimating

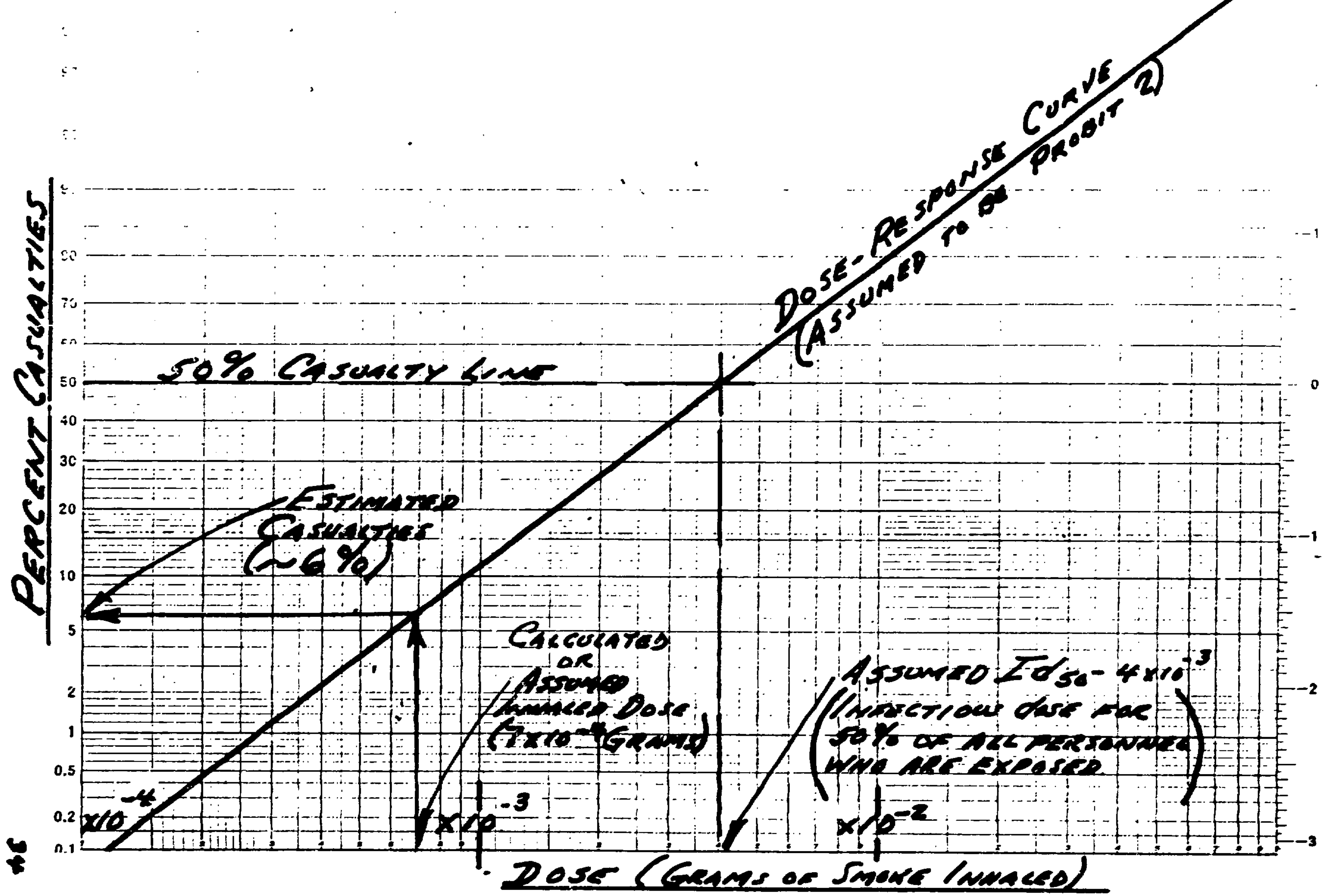


Figure 18 - Casualty Estimating

is more likely to be correct than are the individual calculated values of, say, transmittance.

Smoke generator usage concepts may be evaluated by use of the nomograph, although the process may be laborious compared to use of a computer-programmed model. But the nomograph is intended to be used only as an expedient means to an end by those who do not have convenient access to the computer.

2. Specific

a. Trade-off Analyses: The nomograph is inherently well-adapted to conduct of trade-off analyses. An example is shown in Figure 19. Assumed conditions are: downwind distance of 100 meters, a meteorological condition of near neutral -10 mph wind, and a desired transmittance of .1. The nomograph is shown with solutions for a number of pairs of source strength (burn rate) and extinction coefficient (α) that will satisfy the assumed conditions. Thus, the nomograph solution indicates trade-offs between burn-rate and extinction coefficient, α.

b. Impact Pattern Analyses: There are two techniques for estimating results for a smoke generating weapon such as the artillery rounds which release a quantity of smoke-agent submunitions. The easier way is to assume the total burn rate from all submunitions originates at one point at the centroid of the impact pattern. The other way, more difficult, is to estimate CL for each submunition (using individual submunitions burn rate) at the various downwind distances and then add all the CL's to get a total CL.

It is suggested that the easier method be used with the nomograph. CL's from each submunition are additive at any given line-of-sight, and the more difficult method will probably yield more accurate solutions. But the nomograph is not sufficiently precise to warrant the extra effort.

If the downwind distance from a center-of-impact area is some integral multiple of the impact area diameter, the characteristics of the impact pattern do not have appreciable effect upon estimated CL or transmittance. When the line-of-sight is crosswind and all the way through the smoke, the impact pattern diameter and submunition distribution do not appreciably influence the smoke effectiveness estimates. When line-of-sight is upwind or downwind, however, the impact pattern is all-important. The nomograph will not solve for upwind-downwind scenarios.

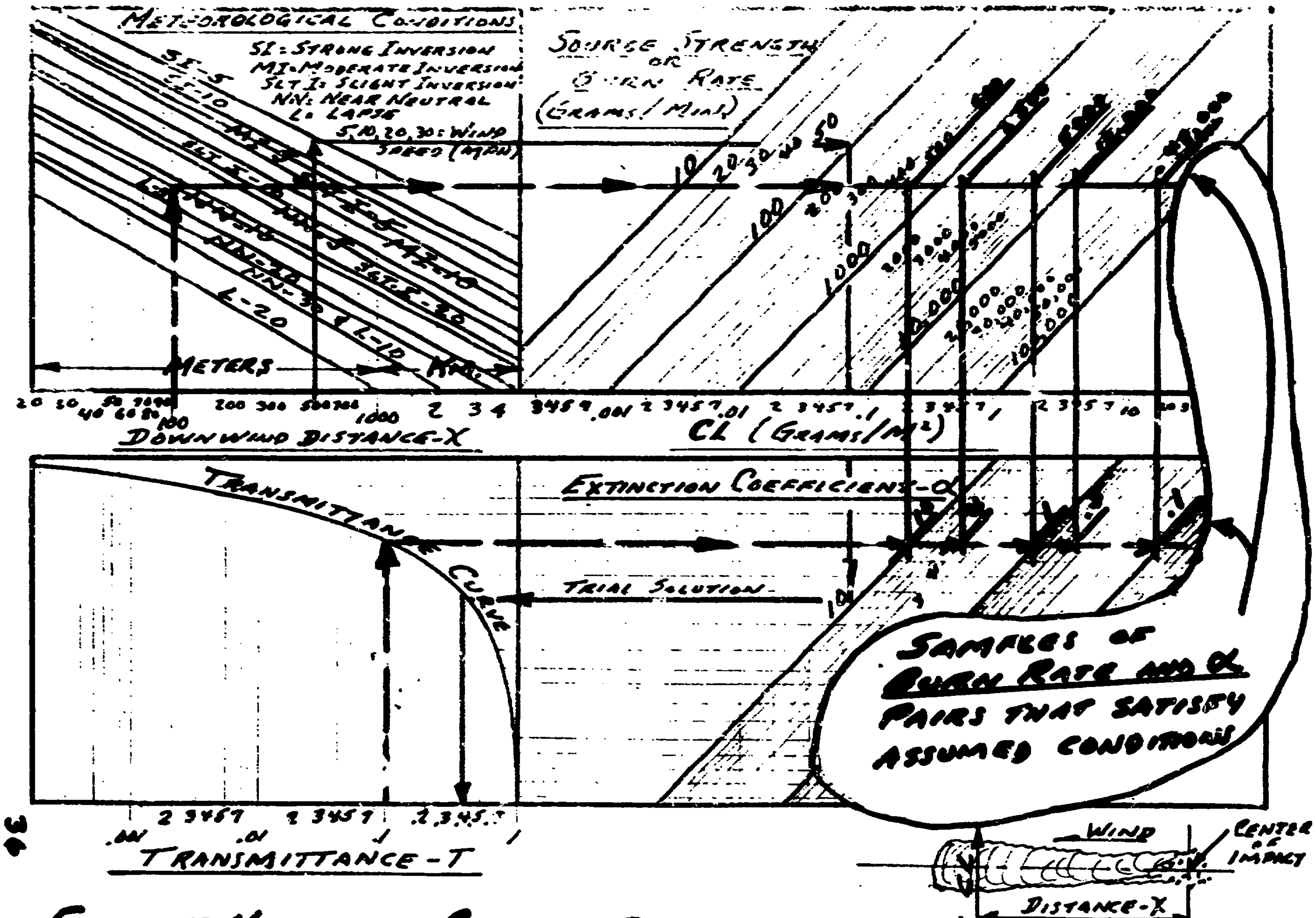


FIGURE 14-NOMOGRAPH SOLUTION-BURN RATE VS α TRADEOFF

Note that CL is directly proportional to burn-rate, and that CL and α determine transmittance. Accuracy of both CL and α are equally important for accurate estimates of transmittance. CL may well be the more critical of the two because it is derived from the model (Calder-Milly) while the α is derived empirically from field or laboratory test values of transmittance and CL. That is, CL is measured (along with transmittance) to calculate the α input to the model, but the CL for nomograph (or computer) is derived from the Calder-Milly (or other) model. This note assumes that field test and laboratory values are more accurate than values derived from models.

V. GENERAL DISCUSSION

This report describes a desk-top expedient for obtaining approximate answers relating to effectiveness of "smoke vs. EO" systems. The expedient, the nomograph, is not intended to be a precise calculator. Precision is probably on the order of that available from a rather short slide rule, which is not much. Perhaps that is all the precision warranted by the model, which to date has not been "validated."

Should those involved in model validation conclude that the Calder-Milly Model is not the one to be used, the chosen model could be substituted in the nomograph. Only a nomographic technique is intended for explanation in this report, but (as shown in Figure 12) the nomograph solutions are not all that remote from real-life results from tests.

One should not take too seriously any "fine-line" performance curves derived from use of the nomograph, or perhaps from any solution of the model. Performance curves such as "transmittance vs. time" should be thought of (if not actually drawn) as wide "magic-marker" lines - - - not fine, sharp lines.

A nomograph drawn on a larger sheet would be easier to use. Perhaps this will be done when the "validated" model is selected. Also, the meteorological-condition portion should have Pasquill category labels rather than those shown. This, too, will probably be done when correlation between the two systems is better established. Another refinement would be the labelling of α curves according to the specific agent and electro-magnetic spectrum - - - such as: "RP at near-IR" instead of a number.

Extent of further effort on this technique will depend upon consensus of opinion relating to its value.